NOTES ON FOUNDRY PRACTICE.

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PREFACE TO SECOND EDITION.

IN this edition the general arrangement and scope of the book have been maintained. The work, however, has been revised, and new matter added.

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J. J. MORGAN.

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PREFACE.

OWING to the fact that foundry practice is such an extensive field and embraces several operations, and since castings vary so considerably in type, it is impossible to give, let alone lay down, any rules the following of which, however closely, would result in obtaining, in all cases, satisfactory work. Successful founding is not dependent on any one operation or factor alone, but on several, and it does not follow that because metal of a correct composition is used a good casting will be the result. The composition and form of the mould, the temperature of casting, and other important details, each of which varies with different castings according to their weight, the strength required, etc., have an influence. Indeed, founding is an art requiring considerable knowledge which can only be acquired by lengthy practical experience, and, in addition, the exercise of considerable skill and forethought.

From the foregoing it will be evident that it is impossible within the limits of this little work, written at the request of the Publishers, to give more than a general description of the methods of founding, and the author's aim has been to provide, as far as the scope of the work permits, condensed and reliable

information as to the materials used and the methods followed in, more particularly, iron founding, and, more briefly, steel, brass, bronze, and phosphor-bronze casting, for those engaged in foundries, technical students, metallurgists, draughtsmen, engineers, and others.

The author wishes to acknowledge the valuable information he has obtained from the standard works of McWilliam and Longmuir, Turner, Harbord, West, Sharp, and Keep; the *Journals* of the Iron and Steel Institute, Cleveland Institute of Engineers, and South Staffordshire Iron and Steel Institute. He is also under obligation to the several manufacturers who have furnished the analyses of their pig-irons; to Messrs Thwaite Bros., Bradford, for permission to reproduce figs. 5, 7, 8, 9, and 10, and for the blocks used for figs. 3, 4, and 6; and to the Publishers for fig. 1, which is taken from McWilliam and Longmuir's *Modern Foundry Practice*.

J. J. MORGAN.

June 1912.

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NOTES ON FOUNDRY PRACTICE.

§ 1.—PIG- OR CAST-IRON.

Pig- or Cast-Iron, the semi-manufactured product of the blast furnace, varies in chemical composition, properties, and the uses to which it is put. As is well known, the base of all pig-iron is metallic iron, with which is usually associated varying percentages of carbon, silicon, sulphur, phosphorus, and manganese, and, in addition to the foregoing, not infrequently arsenic, copper, chromium, and titanium. In the liquid state it may be considered to be a saturated solution of carbon, silicon, etc., in iron, but in what form it is impossible to say. In many cases it may be already as compounds which crystallise out on cooling, or it may be that the compounds are formed during solidification, or during the subsequent cooling. The presence of these non-ferrous elements is accidental, and is due to their being contained in, and reduced from the raw materials (ore, fuel, etc.) from which the iron is made, and the percentages present vary with the nature of the charge, the working conditions of the furnace, etc. Phosphorus, however, remains practically constant in iron made from the same raw materials. These elements affect the pro-

perties of the iron, some to a greater extent than others, depending on the amounts present, and also on the state in which they exist, whether free or in chemical combination.

A chemical compound in a metal is generally a hard and brittle substance, and it may reasonably be assumed that it imparts its properties, if not entirely, at least to some extent, to the metal in which it is contained—in this case iron. Carbon, silicon, phosphorus, and sulphur form chemical compounds with iron, but manganese does not. Manganese, also, forms compounds with carbon, silicon, sulphur, and phosphorus.

The properties of cast-iron are not entirely dependent on the chemical composition, as the rate of cooling, initial temperature of casting, etc., have considerable influence.

CARBON.—The carbon present in cast-iron is derived from the fuel necessary for the reduction of the oxide of iron of the ores to the metallic state, etc. It directly influences the physical properties of the metal to a greater extent than any other of the constituents, and exists in several forms, but two distinct varieties are generally recognised, viz. "combined," and "free" or "graphitic" carbon (also known as "graphite"). In soft grey iron it is mainly present in the free or graphitic state, and in white iron as combined carbon.

Carbon has a strong affinity for iron, but there is a maximum quantity (according to Turner 4·25 per cent.) which molten iron can dissolve, or hold in solution. The solvent power of iron for carbon is influenced by temperature and time, and by the nature and amount of the other elements present.

Silicon tends to reduce the solubility of carbon in iron, so that with a silicon content of 20 per cent., carbon is nearly wholly absent. Manganese and chromium, on the other hand, raise the saturation-point. With about 80 per cent. of the former the iron can hold 7 per cent. of carbon, with 75 per cent. of chromium, 14 per cent. of carbon can be dissolved. Temperature also affects the amount of carbon which iron is able to hold in solution, and the quantity thus held by molten metal is much larger than when in the cold state.

The amount of carbon entering the iron is not affected to any great extent by the condition of the furnace, neither is it dependent on the composition of the charge.

Total Carbon.—In the molten metal it is generally accepted that the carbon is wholly present in the combined state, and as the metal cools the carbon is more or less completely thrown out, or precipitated as graphite, any excess above the saturation point separating out as "kish." The proportions in which the two forms of carbon exist in each state are subject to considerable variations, being affected by the presence of the other elements, the rate of cooling, initial temperature,[1] etc. Silicon and aluminium favour the separation in the free or graphitic state, while manganese and sulphur have an opposite effect. From this it will be seen that two irons may contain the same amount of *total carbon*, yet different proportions of free and combined carbon.

The strength of cast-iron varies with the amount and the condition of the carbon. Up to a certain point

[1] The higher the initial temperature of the metal the greater the amount of heat imparted to the mould, and consequently the cooling is prolonged.

the change of graphite into combined carbon would strengthen the iron, but beyond this point any further change would weaken the metal. The total carbon in foundry iron usually ranges from 3 to 3½ per cent.

Combined Carbon.—Of the several constituents of cast-iron, combined carbon, that is the carbon remaining in combination with the iron after the separating out of the graphite, has probably the greatest effect on the properties of the metal, and is the principal factor in determining its hardness, ductility, tenacity, and behaviour during solidifying, and hence the ease with which it may be cast, and the soundness of the castings. It exists in at least two conditions, viz. in segregated patches as a carbide of iron, cementite, having the formula Fe_3C, containing 6·66 per cent. of carbon, and in fine striations as pearlite, a constituent made up of an intimate mixture of ferrite (pure iron) and cementite, containing 0·69 per cent. of carbon, and represented by the formula $2Fe + Fe_3C$.

The presence of these two carbides is probably brought about as follows:—First of all, the carbon unites with the iron in the proportions of 1 of the former to 14 of the latter, forming the carbide of iron, cementite. Then the iron in excess of that required to combine with the carbon to form cementite unites with the cementite, in the proportions of 7 to 1, in alternate layers, forming a eutectoid alloy termed pearlite. With an iron containing about 0·9 per cent. of combined carbon, all the carbon is present as pearlite; below this figure pearlite and a residual network of ferrite occurs, and above the figure pearlite and a residual network of cementite. The

pearlite crystallises in polygonal grains, and it is along the edges of these grains or crystals that the excess of cementite or ferrite collects as a network. The proportions of combined carbon existing as pearlite is influenced slightly by phosphorus, and less so by the other non-ferrous elements.

Cementite, which is the hardest constituent of cast-iron, is not necessarily a pure carbide of iron, as the iron may be replaced more or less by the other metals associated with the iron, and double carbides formed. Pearlite is a very strong substance, while ferrite, being pure iron, is tough, soft, and weak.

Combined carbon closes the grain, and hardens the iron, and the hardness is almost proportionate to the amount present. It also governs the chill, and as the combined carbon increases, so also the depth of the chill. As a rule the higher the combined carbon, the greater the shrinkage.

For castings of about 1 inch square section, the following percentages of combined carbon are usually suitable for the purposes specified :—[1]

	Combined Carbon.
Extra soft siliceous grey iron .	0·08
Soft cast-iron . . .	0·15
Maximum tensile strength . .	0·47
" transverse strength .	0·70
" crushing strength	over 1·00

The figures will, however, vary somewhat with the size of the casting and the proportions of the other elements present.

Graphite.—Graphite is the practically pure carbon in the free state, which has separated out from the

[1] Turner, *Metallurgy of Iron.*

molten iron during and after solidification, and after it has become solid and is still cooling. In cast- or pig-iron it exists as flakes generally interposed between the grains of metal in all directions. During the cooling of the liquid metal to the temperature of, and at the moment of, solidification the graphite separates out as plates or crystals varying in size with the initial temperature, and the rate of cooling (this is influenced by mass, such as the size of the pig or casting), and the slower the cooling the larger the plates or crystals. On cooling from the temperature of solidification to that of the surrounding air, the graphite is precipitated in a non-crystalline, finely divided state, and this variety is termed "temper graphite." Silicon favours the precipitation of the carbon as graphite, but the proportion necessary to effect this varies according to the amount of total carbon present, and, more particularly, with the proportions of sulphur, manganese, etc. Silicon also favours the separation of graphite as temper graphite.

The influence of these two varieties of graphitic carbon is different. Graphite as crystals or plates opens the grain, *i.e.*, gives softness of texture, and renders the metal weak as distinguished from brittleness, the weakening being due to:—

(*a*) The graphite plates being of themselves weak and showing decided cleavage.

(*b*) The breaking up of the continuity of the matrix (which in the case of cast-iron is an alloy of carbon and the other elements). This will be evident if we consider pig-iron to consist of graphite surrounded by a matrix of a metallic alloy.

Temper graphite, which is present in considerable

proportions in all strong irons, gives softness, combined with closeness of texture and strength.

It has been already stated that silicon favours the separation of carbon as graphite. Adamson[1] and others, however, hold that the separation may be largely of a thermal nature, that is, due to the temperature of manufacture and of casting; while from Saniter's[2] experiments it would appear that the separation of graphite is greater the higher the total carbon, the separation being facilitated by the greater length of time the metal is kept at a high temperature. Charpy and Grenet[3] conclude:—

(*a*) That the higher the silicon the lower the temperature at which graphite separates.

(*b*) That once it has commenced, the separation may continue at a lower temperature.

(*c*) That at a constant temperature the separation of graphite is slower with a low temperature than with a high temperature, and also with low silicon than with high.

The general effect of graphite is to open the grain, reduce the chill and shrinkage, and raise the melting-point of the iron.

The softness of grey iron is not due to the presence of graphite, but to the absence of cementite.

SILICON.—This element is found in cast-iron in quantities varying from a few tenths per cent. up to 4½ per cent., and is present as silicides of iron and manganese. Its presence in iron is due to the reduction, during smelting, of the silica, SiO_2, contained in the materials from which the iron is made, and the

[1] *Journal Iron and Steel Inst.*, part i., 1906.

[2] *Ibid.*, part ii., 1897.

[3] *Engineering*, vol. lxxiii. p. 626.

quantity reduced is dependent upon the temperature, quantity of flux, and the working conditions of the blast furnace. Since it tends to exclude carbon, and to induce the separation of carbon as graphite, silicon is usually looked upon as a softener. On pure iron it exerts a hardening influence, although to a lesser degree than carbon. There is, however, a limit for the silicon content, beyond which it makes the metal crystalline and brittle, and for general foundry practice 3 per cent. is about the maximum. From this it will be evident that silicon is both a hardener and a softener. Although, generally speaking, the higher the silicon the lower the sulphur, and *vice versa*, this is not necessarily the case, as iron is made which is both low in silicon and sulphur. Besides being favourable to the separation of graphite, silicon influences the size of the graphite plates, and it has been found that on adding silicon to a hard iron the freshly precipitated graphite is smaller than that which exists in ordinary soft iron. The general effect of silicon is to reduce the carbon saturation-point of iron, to raise the melting-point, lessen the shrinkage, increase the tenacity, and decrease the ductility. By combining with oxygen it also tends to prevent blowholes, thus producing sound castings.

In foundry practice the proper regulation of the silicon is most important, not only because of its own influence on the properties of the metal, but also on account of its influence on the carbon. It is not practicable, however, to fix an amount which shall be suitable for every variety of work, as the quantity varies with the size of casting, and according to the percentages of the other elements present. As a

rule, the lower the silicon, the weaker the small and the stronger large castings become, and the higher the silicon the stronger the small and the weaker the large castings become. For grey castings the silicon should not exceed 3·0 per cent. and not fall below 0·80 per cent. McWilliam and Longmuir[1] give the following silicon contents as suitable for the given types of castings, the other constituents being normal:—

	Silicon per cent.
Malleable cast-iron	0·6 to 0·8
Chilled grey iron casting	0·75 to 1·0
High pressure cylinders, valve bodies, etc.	1·3
General machine and engine details, gearing, etc.	1·5
Soft engineering and mill-wright castings, pulleys, etc.	2·5
Soft thin castings, stove grate and similar work	2·5 to 3·0
Hollow ware	3·0 to 3·5

The results of Turner's[2] experiments show that the influence of silicon on the crushing, transverse, and tensile strength respectively is of a uniform character, and he found under the conditions of his experiments that the proportions of silicon, corresponding to the several properties, were as follows:—

	Silicon per cent.
Maximum hardness	under 0·80
Crushing strength	about 0·80
Modulus of elasticity	„ 1·00
Density in mass	1·00

[1] *General Foundry Practice.* [2] *Journal Chemical Society*, 1885.

	Silicon per cent.
Combined crushing and tensile strength; transverse strength	about 1·40
Tensile strength	1·80
Softness and working qualities	2·50

From what has already been said of the effect of silicon in regulating, to an extent, the amount of the combined carbon in the metal, it will be seen that it may be employed as a means of opening the grain and softening the iron. It is best added as a highly siliceous iron, as if used in the form of ferro-silicon the diffusion is not so good, partly due to the difference in the melting points of the alloy and iron, and partly to the small quantity of the alloy required to bring about the desired result. Its use requires the exercise of discretion and judgment, and due regard to the composition of the iron, as the addition of either too much or too little may produce hard and brittle metal, and unsound castings.

SULPHUR.—As a sulphide of iron, FeS, or manganese, MnS, or possibly in both forms, sulphur is contained in cast-iron in quantities from a hundredth or so per cent. up to several tenths per cent. In the absence of manganese, iron sulphide is formed, while if the metal contains manganese, which it nearly always does, the sulphur unites with it in preference to uniting with the iron. With an insufficiency of manganese to satisfy the whole of the sulphur, the excess of the latter combines with the iron, so that both sulphides may be present. Of the sulphides, iron sulphide is the more objectionable, as it is readily fusible, and decomposes at high temperatures, gaseous sulpur compounds being given off, which, as they

escape, give rise to blowholes, and therefore cause spongy, unsound, and weak metal. Further, being readily fusible, it is probably the last constituent to solidify, and, as a result, it tends to be unevenly distributed and segregates in the middle and upper parts of the casting. Manganese is not so readily fusible, and the temperature of decomposition is higher. Sulphur neutralises the effect of silicon (one part of sulphur neutralises from ten to twenty-five parts of silicon), and keeps the carbon in the combined state, thereby increasing the hardness and shrinkage of the metal and also the chill ("sulphur chill" is not to be desired). It increases the fusibility and liquidity of the metal, and much sulphur, in the absence of manganese and a high casting temperature, causes blowholes. Sulphur tends to increase the contraction and hardness, and brittleness. The amount of sulphur allowable is difficult to fix, and is governed by the silicon content, but the founder is wise to exclude it as much as possible, and in no case should it much exceed 0·10 per cent. For soft fluid castings 0·04 per cent. is about the maximum, and for strong castings 0·07 per cent. gives good results. For strong castings, such as cylinders, it has been found that sulphur up to about 0·11 per cent. gives the greatest wearing properties. Metal very low in sulphur is generally too soft, and wanting in strength and rigidity.

PHOSPHORUS.—Phosphorus, which is present as phosphide of iron, Fe_3P, although tending to exclude carbon, has no effect, in the proportions usually found in cast-iron, on the condition of the carbon. Phosphorus lowers the melting-point of cast-iron, prolongs the period during which it remains fluid,

and gives a very fine skin to the metal, hence the use of phosphoric iron for fine detail castings, where strength is of secondary importance. Small quantities of phosphorus increase the strength, but with large quantities the phosphide remains fluid after the main bulk of the iron has solidified, and being deposited throughout the mass in isolated globules, varying in size with the rate of cooling, causes weakness. Phosphorus, on the other hand, tends to eliminate blowholes, thereby promoting soundness; it decreases the shrinkage, but does not materially affect the hardness; it reduces the amount of total carbon, and makes the metal more fusible, more fluid, and causes it to remain fluid longer when melted. For strong castings the phosphorus should not exceed 0·60 per cent., while for general foundry work, where strength is not of great importance, 1 to 1·5 per cent. may be allowed. Beyond the higher limit the metal is very hard and weak.

MANGANESE.—As already stated, manganese increases the solvent power of iron for carbon, and promotes the retention of the carbon in the combined form as carbide of manganese, which possesses the same tendency as carbide of iron to close the grain, increase the hardness, shrinkage, and chill. Keep shows that an increase of 1 per cent. of manganese over the quantity usually present increases the hardness 40 per cent., and the shrinkage 26 per cent. Up to 1 per cent. it does not materially affect the properties, except perhaps to slightly lower the deflection. Manganese combines with sulphur to form manganese sulphide, and thus acts as a softener by counteracting the effect of sulphur, and prevents blowholes by increasing the solvent power of iron for gases.

To obtain metal having the lowest friction coefficient, such as for slide valves, motion bars, etc., Sharp[1] recommends the use of iron containing 2 to 3 per cent. of manganese.

In a paper on "Cast-Iron in Theory and Practice," read before the Manchester Association of Engineers (and *The Iron and Coal Trades Review* of 16th January 1920), E. Adamson gives a series of tables as evidence that silicon does not control the mechanical tests of cast-iron, the percentage of total carbon, the ratio of graphitic carbon to combined carbon, or even the fracture of the pig-iron. If anything could be said to "control" the fracture, and, in fact, the analyses of pig-iron also, it was primarily the temperature conditions existing at the time of smelting. Sulphur, he thinks, is much abused, and its influence not understood. Up to 0·10 per cent. is by no means detrimental, and for ordinary castings it was safe to allow 0·15 per cent. without serious harm, depending on the physical characteristics of the pig-iron used. High sulphur was, however, unsuitable in malleable cast iron and chill work. For many classes of work phosphorus up to 1·50 per cent was not detrimental, but in castings which had to be continually exposed to heat in wear, the lower the better. Manganese added to molten iron made for hardness, it also helped to increase the depth of chill and to close the grain, but this latter might be reversed if the manganese was added in the blast furnace. It did not follow that a virgin pig-iron high in manganese must of necessity be a close-grained iron, nor did the high manganese guarantee a "clean" iron.

[1] *Modern Foundry Practice.*

In Table I. the influence of the several constituents on the properties of cast-iron are summarised.

ARSENIC and **COPPER**, although common constituents of cast-iron, are generally present in such small quantities as to have practically no influence on the properties. Arsenic has an influence similar to, although perhaps less marked than that of phosphorus. Copper is sometimes added to give closeness of grain

TABLE I.

	Combined carbon.	Graphitic carbon.	Silicon.	Sulphur.	Phosphorus.	Manganese.
Hardness	×	...	×¹	×	×	×¹
Chill	×	...	—	×	...	×¹
Softness	—	×	×	×	...	×
Weakness	×¹	×	×	×	×	...
Shrinkage	×	...	—	×	—	×
Strength	×	...	—	—	—	×
Soundness	...	...	×	—	×	×
Fluidity	...	×	—	×	×	—

× = Increase. — = Decrease. ×¹ = In excess.

Titanium is a not uncommon constituent, probably as cyanonitride of titanium, and when present imparts a characteristic velvety appearance to the fractured surface. As a deoxidiser ferro-titanium alloy containing 9 to 12 per cent. of titanium is added to the molten metal in the ladle when about half full, and its value as such lies in the removal of not only the occluded oxides, but also the nitrogen and slag. According to Bahlson, a small quantity of titanium increases the bending and the tensile strength.

Aluminium.—It is doubtful whether this element is present in cast-iron. Its influence, when added to iron, either as metal or as ferro-aluminium, is similar to that of silicon, except that it is more energetic. It favours the separation of the carbon in the graphitic state, and, therefore, decreases the chill. It also increases the strength, diminishes the shrinkage, and eliminates blowholes.

When used as a deoxidiser it is added in the same manner as ferro-titanium.

Grey iron melts at a higher temperature than white iron, and as a rule the higher the total carbon the lower the melting-point and the more fluid the iron. The melting together of grey and white irons does not give satisfactory results, as, owing to the lower melting-point, it will usually be found that the white iron comes down first.

§ 2.—GRADING OF PIG-IRON.

Pig-iron is graded or classified as Nos. 1, 2, etc., according to the appearance of the freshly fractured surface, the most open-grained grey iron being the first or No. 1 of the series, and white iron the last extremity. Mottled is an intermediate variety, and is a mixture of grey and white.

No. 1 Pig.—This is the greyest of all the irons. It breaks with a highly crystalline fracture, dark grey or black in colour, and shows large and easily distinguishable flakes of graphite. The iron melts to a very fluid liquid, and, therefore, readily flows into the interstices of the mould. Owing to its crystalline structure, and the large quantity of graphite it con-

tains, it makes weak and brittle castings, and is only used for very light, thin, and ornamental work where strength is not required.

No. 2 Pig.—The crystals are somewhat smaller, the graphite less distinct, the colour lighter, and the fractured surface smoother than No. 1, but is stronger and harder, and less fluid in the molten state. It is used for light castings.

No. 3 Pig.—This iron is still closer grained, and the graphite plates not so distinguishable. It is lighter in colour, the fracture smoother, more compact and dense looking, and it has less fluidity than the lower numbers, but is stronger, harder, and tougher. Either alone or in admixture with other numbers or scrap it is used for heavy and general work.

No. 4 Pig.—Iron of this grade is whiter in colour, stronger, and more lustrous than the previous grades. It has a granular, uneven, and more or less mottled appearance on fracture, and does not flow freely. It is used for very rough and heavy castings, and is especially suitable for making malleable castings. This grade is often divided into two sub-classes, No. 4 foundry and No. 4 forge, of which the former is the greyer and softer. No. 4 forge is the stronger, approaches to whiteness in colour, is hard, and very close grained although still all grey.

Mottled.—This iron is intermediate between No. 4 and white, and consists of a matrix of white iron through which is scattered specks of grey iron. It is used in making strong castings, and for mixing with siliceous irons.

White Iron.—The fracture is close grained, white in colour, and shows no sign of separated graphite.

It is very hard and brittle, and melts at a lower temperature than grey iron. It is very sluggish in flowing, contracts considerably on solidifying, passing through a pasty stage.

All Staffordshire mine-iron is usually graded as follows:—

Nos. 1, 2, 3, and 4.—These are all foundry irons, descending in order of softness.

Nos. 5 and 6.—More suitable for the forge, or chilled castings. They are close grained.

No. 7.—Mottled.

No. 8.—White.

Scotch makers grade their irons as No. 1, No. 3, No. 4, mottled, and white.

American irons are divided into a large number of grades.

From the foregoing, it will be evident that although the fracture may, and does in many instances, afford information as to the chemical composition of an iron, in others, owing to the several causes by which it is affected, it is no guide, and it is the daily experience of those who have dealings with pig-irons that there is too often little connection between the fracture and the chemical composition. Many instances of this could be given, but the following (Adamson, *Journal Staffordshire Iron and Steel Inst.*, vol. xxiv.), although perhaps an extreme example, will be sufficient:—

Fracture.	No 1.	White.
Silicon, per cent. . .	0·35	0·32

It is granted, however, that an experienced man working on irons of which he knows the source and the conditions under which they are produced, is able

to form a very good and often accurate opinion as to their composition. At the same time, undoubtedly, a large number of the failures in the foundry are due to the iron being selected by the fracture.

§ 3.—ANALYSES OF PIG-IRONS.[1]

Cleveland Pig-Iron.[2]

		No. 1.	No. 3.	No. 4. Foundry.	No. 4. Forge.
Graphitic carbon .	%	3·30	3·01	2·80	3·00
Combined ,, .	,,	·15	·27	·48	·62
Silicon . . .	,,	2·90	2·80	2·31	1·53
Sulphur. . .	,,	·03	·04	·08	·14
Phosphorus . .	,,	1·52	1·50	1·55	1·50
Manganese . .	,,	·60	·58	·50	·45

Redbourne Hill Iron and Coal Company, Limited, Frodingham, Lincolnshire.

		No. 1.	No. 2.	No. 3.	No. 4.
Graphitic carbon .	%	3·25	3·20	3·10	2·80
Combined ,, .	,,	·30	·45	·55	·85
Silicon . . .	,,	2·50	2·25	2·00	1·80
Sulphur . . .	,,	·01	·015	·025	·030
Phosphorus . .	,,	1·35	1·35	1·35	1·35
Manganese . .	,,	1·75	1·70	1·65	1·60

[1] In the majority of cases the manufacturers state that the analyses are approximate.

[2] *Iron*, by C. Hood.

The Carron Company, Glasgow.

		No. 1.	No. 3. Special.	No. 3. Soft.	No. 3. Foundry.
Graphitic carbon	%	3·50	3·46	3·35	3·35
Combined „	„	·14	·20	·18	·20
Silicon	„	2·80	2·27	2·65	2·15
Sulphur	„	·035	·045	·038	·060
Phosphorus	„	·70	·701	·699	·700
Manganese	„	1·00	·995	1·00	·908

		No. 3. Close.	No. 3. Hard.
Graphitic carbon	%	3·17	3·16
Combined „	„	·28	·30
Silicon	„	1·75	1·57
Sulphur	„	·065	·070
Phosphorus	„	·705	·710
Manganese	„	·850	·800

Kettering Iron and Coal Company, Limited, Kettering, Northamptonshire.

		No. 1.	No. 2.	No. 3.	No. 4.
Graphitic carbon	%	3·90	3·38	3·35	3·255
Combined „	„	trace	·107	trace	trace
Silicon	„	3·826	2·91	2·613	2·126
Sulphur	„	·009	·004	·009	·020
Phosphorus	„	1·692	1·557	1·793	1·556
Manganese	„	·261	·264	·287	·174

Shelton Iron, Steel and Coal Company, Limited, Stoke-on-Trent.

		No. 1.	No. 2.	No. 3.	No. 4. Forge.	Basic.
Graphitic carbon	%	3·60	3·40	3·25	2·75	...
Combined „	„	·10	·20	·40	·60	3·00
Silicon . . .	„	3·25	2·90	2·47	1·65	·65
Sulphur . . .	„	·02	·03	·035	·055	·060
Phosphorus . .	„	1·10	1·10	1·10	1·00	2·70
Manganese . .	„	2·25	2·00	1·80	1·75	2·75

The Seaton Carew Iron Company, Limited, West Hartlepool.

"Seaton Carew" Foundry Hematite.

		No. 1.	No. 2.	No. 3.	No. 4.
Graphitic carbon .	%	3·75	3·45	3·05	2·70
Combined „ .	„	·30	·40	·55	·70
Silicon . . .	„	2·25	2·00	1·75	1·50
Sulphur . . .	„	·03	·05	·07	·10
Phosphorus . .	„	·045	·045	·045	·045
Manganese . .	„	1·10	1·05	·95	·75

		"S.S.F." Cold-Blast Cylinder Iron.	"S.S.F." Cold-Blast Refined Chilling Iron.
Graphitic carbon .	%	2·82	2·61
Combined „ .	„	·51	·59
Silicon	„	1·12	·68
Sulphur	„	·09	·10
Phosphorus . . .	„	·06	·06
Manganese . . .	„	·56	·51

"S.C.M." Malleable Pig-Iron.

		Grey.	Mottled.	White
Graphitic carbon .	%	2·25	1·75	·22
Combined „ .	„	·95	1·30	2·79
Silicon . . .	„	·81	·70	·49
Sulphur . . .	„	·12	·15	·18
Phosphorus . .	„	·07	·07	·07
Manganese . .	„	·45	·35	·25

West Coast Malleable Refined Pig-Iron.[1]

		Carbon.	Silicon.	Sulphur.	Phosphorus.	Manganese
Grey .	%	3·80	1·25	0·10	0·05	0·10
Mottled .	„	3·45	0·7 to 1·0	0·10 to 0·25	0·05	0·10
White .	„	3·20	0·60	0·30	0·05	0·10

Special Malleable, Brand "Lorne." (Charcoal Cold Blast.)[1]

		Combined Carbon.	Graphitic Carbon	Silicon.	Sulphur.	Phosphorus.	Manganese.
Grey	%	0·88	3·35	0·84	0·015	0·08	0·12
White	„	3·35	.	0·25	0·055	0·112	0·09

[1] Hatfield, *Cast Iron in the Light of Recent Research.*

No. 4 W.Q. Staffordshire Cold-Blast.[1]
P. Williams & Sons, Tipton.

Combined carbon	·50 %
Graphite	2·50 „
Silicon	·93 „
Sulphur	·08 „
Phosphorus	·45 „
Manganese	·56 „

Cold-Blast Cylinder Pig-Iron.[2]
M. & W. Grazebrook.

Combined carbon	·50 %
Graphite	2·60 „
Silicon	1·00 „
Sulphur	·08 „
Phosphorus	·47 „
Manganese	·50 „

Staveley Coal & Iron Co., Ltd. (No. 1 Furnace, Devonshire Works.)[3]

Carbon	3·55 %
Silicon	3·10 „
Sulphur	0·026 „
Phosphorus	1·43 „
Manganese	0·81 „

[1] "Iron and Steel at the Franco-British Exhibition," *Iron and Steel Institute Journal*, 1908, part iii.

[2] *Ibid.*

[3] F. Clements, *Iron and Steel Institute*, and *Iron and Coal Trades Review*, May 7, 1920.

South Wales and Monmouthshire.—Guest, Keen & Nettlefold, Limited, Dowlais, Glamorganshire.[1]

	No. 1.	No 2.	No. 3.	No. 4.	No. 5.	Mottled.	White.
Combined carbon %	·30	·32	·42	·47	·54	1·90	2·88
Graphite . . ,,	3·75	3·50	3·20	2·84	2·52	1·00	·20
Silicon . . ,,	2·20	1·95	1·85	1·50	1·40	·60	·50
Sulphur . . ,,	·025	·035	·055	·08	·135	·20	·26
Phosphorus . ,,	·05	·05	·054	·0053	·052	·054	·052
Manganese . ,,	1·15	1·04	·70	·68	·54	·36	·33

West Coast Hematite.—The Workington Iron and Steel Company, Limited, Workington, Cumberland.

Approximate Analysis.

	B. 1.	B. 2.	B. 3.	Forge.	Five.	Mottled.	White.
Graphitic carbon %	3·50	3·30	3·00	2·75	2·50	1·50	·50
Combined ,, ,,	trace	·25	·50	·50	1·20	1·80	3·00
Silicon . . ,,	From 1 % to 3%			1·75	1·25	1·00	·75
Sulphur . . ,,	Trace	·020	·040	·075	·120	·24	·33
Phosphorus . ,,	From ·015 % to ·050 %			...	...	...	...
Manganese . ,,	From ·10 % to 1·0 %			...	...	...	...

[1] "Iron and Steel at the Franco-British Exhibition," *Iron and Steel Institute Journal*, 1908, part iii.

E. L. Rhead (*The Principles and Practice of Iron-founding*) gives the following as the composition of metal for particular purposes:—

	1	2	3	4	5	6	7	8	9	10	11	12	13
Silicon	1·85	1·5	1·77	1·81	1·86	1·51	1·80	1·90	2·00	1·90	2·21	2·31	2·83
Manganese	0·80	1·00	0·77	0·80	0·65	0·65	1·60	1·30	0·55	0·64	0·71	0·33	0·65
Phosphorus	0·36	0·55	0·63	0·81	0·53	0·33	0 70	0·94	0·90	0·90	0·45	1·175	0·976
Sulphur	0·096	0·075	0·05	0·10	0·09	0·068	0·08	0·09	0·09	0·08	0·08	0·09	0·07
Combined Carbon	0·58	0·50	0·60	0·56	0·58	0·62	0·71	0·54	0·51	0·52	0·45	0·26	0·53
Graphite	2·50	2·50	2·63	2·78	2·84	2·45	2·30	2 75	2·60	2·75	3·20	2·75	3·10

No. 1 is a typical strong iron of high tensile strength and good foundry quality, yielding sound, strong castings, and is sufficiently fluid for heavy and moderately heavy work. It is the average analysis of metal yielding the best results over a considerable period.

No. 2 is the analysis of typical strong foundry iron for engineering purposes given by Prof. Turner.

No. 3 is a strong close metal.

No. 4 was used for cylinder work. It is a strong, tough, close, non-porous metal

Nos. 5 and 6 were used for similar purposes, the latter for heavier work than 4 and 5.

No. 7 is a close metal which will run in thin castings. Has been used for cylinders for high piston speed, both steam and internal combustion. All bore, turn, and otherwise machine well, and if properly treated yield sound castings. This metal glazes well on the machine.

No. 8 is a strong iron which was used for heavy machinery, and is fairly good.

No. 9, another for the same purpose.

No. 10, used for heavy castings, lathe beds, etc., would be better with less phosphorus. Has a slight tendency to sponginess where parts are kept hot for a long time.

No. 11, for light work, where strength, toughness, and resistance to shock were necessary; fluid and grey down to 1 inch diameter.

No. 12, used for light plate work.

No. 13, for light work of uniform thickness: casts soundly, strong, and shows little distortion. Quite unsuitable for use where large variations of thickness.

§ 4.—GRADE AND CHEMICAL COMPOSITION.

The several grades or Nos. of pig-iron differ in chemical composition, as the Nos. increase, and the four constituents, combined carbon, graphitic carbon, silicon, and sulphur, show a more or less regularity in variation. For a given type of iron, phosphorus remains fairly constant, while manganese, on the other hand, is somewhat irregular. Taking first of all combined carbon, it will be found that in a No. 1 iron it is at its minimum, and gradually increases throughout the series to white iron, which contains the maximum. Graphitic carbon is highest in No. 1 iron, and gradually decreases until, in white iron, the whole of the carbon is in the combined state. Silicon is highest in No. 1. iron and lowest in white, while sulphur is the opposite, being highest in white iron.

Unreliability of Fracture as a Guide to Chemical Composition.—Grading by fracture is really in effect grading by the carbons, as the openness or closeness of the fracture depends on the proportions of combined and free or graphitic carbon respectively present. Since silicon tends to favour the precipitation of carbon in the free or graphitic state, it might be reasonably supposed that the chemical composition of an iron, especially as regards the silicon content, and also the sulphur, since a high silicon is usually accompanied by a low sulphur and *vice versa*, may be determined from the appearance of the fracture--the more open the fracture the more siliceous and less

sulphury the iron. It must be borne in mind, however, that the proportions of the total carbon, which will exist in the combined and graphitic states respectively, are not governed entirely by the silicon content of the iron, but also by the quantity of the total carbon present, the presence of other constituents, some of which have one effect and others the direct opposite, the initial temperature, and the rate of cooling.

§ 5.—SPECIFICATION OF AMERICAN FOUNDRY IRON.[1]

Special Hard Iron (Close Grained).

Silicon must be between 1·2 and 1·6 per cent.; below 1·2 the metal will be too hard to machine; above 1·6 it is liable to be porous unless much scrap be used.

Sulphur must not exceed 0·085 per cent., and any casting showing on analysis 0·115 or more of sulphur will be the cause for rejectment of the entire mix (above 0·115 per cent., sulphur produces high shrinkage, shortness and "brittle-hard" iron. Exceptionally, however, as for frictional wear, in brake shoes, etc., the sulphur may run up to 0·15 per cent.).

Phosphorus should be kept below 0·7 per cent., unless specified for special thin castings. (High phosphorus gives brittle castings under impact.)

Manganese should not be above 0·7 per cent., except in special chilled iron.

[1] *Report of the British Iron Trade Commission*, 1902.

Medium Iron.

Silicon to be between 1·4 and 2 per cent. (Silicon at 1·5 gives the best wearing result for gears.)

Sulphur must not exceed 0·085 per cent., and any casting showing on analysis 0·095 per cent. or more of sulphur will be the cause for rejectment of the entire mix. (Sulphur preferred at 0·075 to 0·08 per cent.)

Phosphorus should be kept below 0·7 per cent., except in special work.

Manganese should be below 0·7 unless otherwise specified.

Soft Iron.

Silicon must not be less than 2·2 nor more than 2·8 per cent., with a preference for about 2·4. (Below 2·2 per cent. small castings will be very hard; above 2·8, large castings will be somewhat weak and have an open grain.)

Sulphur in no case must exceed 0·085 per cent. High sulphur makes iron "brittle-short" and causes excessive shrinkage.

Phosphorus should be kept below 0·7 per cent., except in cases where great fluidity is required, as in thin stove plate, when it may run up to 1·25 per cent. Phosphorus makes iron brittle under impact.

Manganese should be kept below 0·7 per cent., except in chilled work. For a heavy chill the manganese may vary from 0·7 to 1·25 per cent.

Irons used by the American Committee on Standardising Testing of Cast-Iron.[1]

Type of casting.	Silicon.	Sulphur.	Phosphorus.
	%	%	%
Novelties	4·19	0·080	1·336
Stove plate	3·19	0·084	1·160
Cylinders	2·49	0·084	0·839
Light machinery	2·04	0·044	0·578
Heavy "	1·96	0·081	0·522
Dynamo frames	1·95	0·042	0·405
Ingot moulds	1·67	0·032	0·095
Car wheels	0·97	0·060	0·301
Chilled roll	0·85	0·070	0·482
Sand roll	0·72	0·070	0·454

Suggested Limits of Composition based on Size of Casting.[2]

Thickness of section.	Silicon.	Phosphorus.	Manganese.	Sulphur.
	%	%	%	%
Under ¼ inch thick	3·25	1·00	0·40	0·025
¼ to ½ " "	2·75	0·80	0·40	0·040
½ to ¾ " "	2·50	0·00	0·50	0·050
¾ to 1 " "	2·00	0·70	0·60	0·060
1 to 1½ " "	1·75	0·65	0·70	0·070
1½ to 2 " "	1·50	0·60	0·80	0·080
2 to 2½ " "	1·25	0·55	0·90	0·090
2½ to 3 " "	1·00	0·50	1·00	0·100

[1] *Journal American Foundrymen's Association*, x, part ii.
[2] *Iron Age*, February 15, 1906.

SCRAP.—In addition to pig-iron foundry scrap is largely used in the mixtures. It comprises light shop scrap—gates, runners, etc.; heavy shop scrap, such as heavy runners, wasters, etc.; light and heavy machinery scrap; and common scrap. As is obvious the composition will vary considerably, and for this reason it must be carefully selected. During melting, silicon is readily oxidised by oxide of iron, therefore scrap heavily rusted is not desirable. Scrap is employed with the objects of (1) using it up; (2) reducing the cost of the mixture; and (3) if high in silicon and otherwise suitable, as a means of opening the grain and softening the iron. According to E. L. Rhead,[1] light machinery, heavy machinery, and common scrap may be taken as containing:—

Light Machinery.

Silicon . . 2 to 2·5 per cent.
Phosphorus, up to 1 per cent.

Heavy Machinery.

Silicon . .	1·8 to 2·0 per cent.
Carbon . .	3 to 3·2 per cent., of which 0·5 to 0·6 per cent. is combined.
Phosphorus .	0·8 per cent
Sulphur . .	0·1 ,,
Manganese, under	0·6 ,,

Common.

Phosphorus, as much as 1·5 per cent.
Silicon . . 1·5 to 3·5 per cent.
Sulphur, . up to 0·25 per cent.

§ 6.—SHRINKAGE.

Molten iron in cooling contracts until the temperature of solidification is reached, and in cooling from this

[1] *Principles and Practice of Iron-founding.*

temperature to that of the surrounding air it expands. Some irons contract more regularly than others, and Keep found that whereas white iron contracted almost uniformly, grey iron, on the other hand, gave three distinct expansions before the final expansion began. The net result, however, is that a casting is always smaller then the pattern from which it is made, and it is usual when making a pattern to make an allowance of $\frac{1}{8}$ inch per foot on light castings and $\frac{1}{12}$ inch on heavy, for shrinkage. The shrinkage is always greater in the direction of length and breadth than in that of thickness and depth. The shrinkage of castings is not uniform, and varies with the character of the metal and the mass or area of section of the castings, being greater with light parts which cool more rapidly than with heavy parts which cool more slowly. (White irons contract more than grey, which has the minimum shrinkage.) Shrinkage generally varies with the hardness, and, as the latter is largely governed by the silicon, it follows that the shrinkage depends upon the silicon content. Table II. (Keep's *Cast Iron*) shows the influence of variable silicon content and area of section on the shrinkage.

TABLE II.

Size of Bar.	Contraction per Foot.					
	$\frac{1}{2} \times \frac{1}{2}$ in.	1×1 in.	1×2 ins.	2×2 ins.	3×3 ins.	4×4 ins.
Silicon, . . . 1 %	0·183	0·158	0·146	0·130	0·113	0·102
,, ... 2 ,,	0·159	0·133	0·121	0·104	0·085	0·074
,, . . . 3 ,,	0·135	0·108	0·095	0·077	0·059	0·045
Ratio $\frac{\text{Surface}}{\text{Volume}}$	0·125	0·250	0·333	0·500	0·750	1·00

The temperature at which the metal is poured also has an influence.

The usual allowances for shrinkage are :—

Metal.	Allowance.
Grey cast-iron . .	$\frac{1}{8}$ inch per foot.
White " . .	$\frac{1}{8}$ " "
Steel . . .	$\frac{3}{16}$ " "
Gun-metal . .	$\frac{3}{16}$ " "
Brass (yellow) . .	$\frac{1}{8}$ " per 10 inches.

§ 7.—CHANGES DUE TO REMELTING.

Iron on remelting undergoes both chemical and physical changes, and the two most important factors which alter the chemical composition are (1) the blast, which tends to decrease certain of the constituents, and (2) the fuel, which leads to the increase of some of the constituents.

Carbon may be either decreased or increased, according to the conditions. The oxygen of the blast tends to eliminate carbon, and the longer the exposure to, and the higher the pressure of the blast, and the higher the carbon, the greater the loss. On the other hand, long contact of the molten metal with coke at high temperatures may lead to the absorption of carbon. Silicon is decreased by oxidation to silica (SiO_2), and the loss varies with the amount of silicon present and the length of exposure. Loss of manganese is brought about by oxidation, and by combining with sulphur and entering the slag as manganese sulphide (MnS). Generally, the higher the sulphur the greater the loss of manganese through this cause. The sulphur increases, due to absorption

from the fuel. As a rule the phosphorus remains constant, although there is a possibility of its being increased by absorption from the fuel.

No fixed data can be given as to the actual losses and gains which will be encountered in melting cast-iron, as they will vary with the conditions—such as the grades of iron, the volume and temperature of the blast, the composition of the fuel, and the construction of the cupola. Every founder must determine these for himself under his own conditions of working. As a rule, however, unless the total carbon is abnormal, it will remain much the same; if abnormally low it will tend to increase. The silicon decreases to the extent of 0·2 to 0·3 per cent.; manganese may suffer a loss of 0·2 to 0·3 when present to the extent of 1 per cent., with a low content, however, the decrease may be practically nil. The iron generally takes up 0·03 per cent. of sulphur, but in the presence of an abnormally high quantity of manganese it may actually decrease.

§ 8.—MOULDING SANDS.

Moulding Sands consist chiefly of quartz or free silica and clay, together with variable amounts of iron oxide, lime, magnesia, and alkalies (sodium and potassium compounds). The refractoriness, porosity, and shrinkage of a sand are governed by the free silica or quartz, and the binding property or cohesiveness by the clay. The other constituents may be considered as impurities, as quartz and clay, provided they are in the proper proportions, of them-

selves constitute a good moulding sand. The requirements in a moulding sand are:—

(a) **Refractoriness**, that is, the property of withstanding without fusion the temperature of the molten metal with which it comes in contact. There are several factors which govern this property: (1) A high percentage of quartz or free silica. Pure silica is very refractory, having a softening point of about 1930° C., and, therefore, the higher the silica the greater the heat-resisting property of a sand. (2) The size of the quartz grain. A sand of comparatively large grain is more refractory than one of small grain. (3) Freedom from impurities. Iron oxide, lime, and magnesia, all tend to increase the fusibility. The alkalies are generally present in small quantities, and, being fusible at a low temperature, tend to flux the rest of the sand and bind it together. Lime, present as carbonate, evolves gas at high temperatures, producing rough surface casting.

(b) **Bond, Cohesiveness**, or **Strength** is the property of being easily rammed into shape, so as to accurately retain the form of the pattern imbedded in it on withdrawal of the latter, and of withstanding the abrading action of a stream of liquid metal. As previously stated, the bond of a sand is clay, which, however, is seldom pure but is generally mixed with impurities which weaken its binding properties. Pure clay consists of silica 46·4 per cent., alumina 39·7 per cent., and combined water 13·9 per cent., and it is to the combined water that a clay

owes its cohesive or binding properties. If a clay is heated to a high temperature the combined water is driven off, and it loses its binding properties, so that, no matter what amount of water is added, it will not regain its cohesiveness, and the clay is said to be burnt. On the other hand, if a clay is heated or dried at a temperature insufficient to drive off the combined water, but sufficient to expel the moisture or accidental water, the cohesiveness is not destroyed, and on mixing with water and subjecting to pressure it will retain the form on withdrawal of the pressure. So, too, with moulding sands. Sands are classified as weak, medium, and strong according to the percentage of binder or bond (that is clay) they contain; the lower the amount of clay the weaker the sand. In practice a sand with as low a clay content as is consistent with the character of the work in hand should be chosen, since much clay destroys the porosity, and causes shrinkage and cracks. For light castings a weak sand is used; for medium castings a medium sand; while for heavy castings a strong sand is employed. Want of binding may be remedied within limits by the addition of clay-water.

Longmuir gives the following as suitable alumina contents in moulding sands:—

Type of casting.	Alumina per cent.
Light brass	12
Heavy brass and light iron . .	10
Medium iron	8
Heavy iron	6

The shape of the quartz grains also affects the strength, and sands with grains having jagged exteriors will be stronger than sands having smooth grains.

(*c*) **Porosity**—that is openness, to allow of the ready escape of the air, gases, and moisture present in and generated in the mould on pouring the liquid metal. Clay being non-porous, and baking when heated tends to reduce the porosity. This property is also influenced by the proportion of quartz to clay, and, generally speaking, the higher the proportion of quartz the more porous the sand will be. Both the size and shape of the quartz grains have an influence, and the larger and more irregular in shape the grains, the more porous or open the sand. There is, however, a limit to the size of the grain, as too large a grain does not give a good finish to the casting. Comparatively fine grains of a uniform size will give a more porous sand than one consisting of a mixture of large and fine grains.

(*d*) **Easy removal** from the cold casting, to which it should give a smooth and clean surface. These properties are associated with the refractoriness and the size of the grains.

(*e*) **Resistance** to the searching or penetrating action of the liquid metal. The metals differ in their searching or penetrating action, and a sand which, with liquid iron, would give a casting easily cleaned, would, on the other hand, with lead, although poured at a much lower temperature, give a casting to which the sand would adhere most tenaciously. This property is associated with porosity.

(*f*) **Plasticity**—the property of readily shaping itself to the form of the pattern.

Sands are said to be "open," "close," "weak," or "strong" according to their porosity and binding properties. A sand that is "open," that is porous, may be "weak" or wanting in binding or bond, and *vice versa*, a "strong" sand, that is one that binds well, may at the same time be "close" or deficient in porosity. "Sharpness" is the term applied to lack of cohesion or bond. River sand is an example of sharpness.

Moulding sands may be divided into, (1) facing sand, that is the sand which comes into direct contact with the pattern, and is used for the purpose of giving to the casting a clean, smooth surface; (2) "black" or "floor" sand, which does not come into contact with the pattern, but is employed to complete the mould, giving it rigidity and a porous backing; (3) "parting" sand, which as the name implies is employed to separate the several divisions of a mould; (4) "core" sand; and (5) loam.

The grade of a moulding sand is determined by the size of its grain. For light work the finer grained sands are employed.

Green Facing Sands.—The term "green" has no reference to the colour of the sand, but is applied to the sand in its raw, natural, or green state. The red sands of Belfast, Mansfield, Staffordshire, and the yellow sand of Erith are types of the sands employed as facings. The sands are ground or milled, sieved, and for iron casting mixed with coal-dust, powdered charcoal, coke-dust, etc, which is added to assist in peeling the sand from the casting. The strength and fineness of the facing sand used varies with the

character of the work, and for light ornamental work with intricate detail of design a strong and very fine-grained sand is employed. For light work with a plain surface a weaker sand may be used, and black or floor sand mixed with coal-dust gives good results. For work of comparatively thin section and large surface the coal-dust and sand are used in the proportions of a shovelful of the former to a riddle of the latter. It is not necessary with all classes of work to use new sand for facings, and a mixture of equal parts of new and black sands with coal-dust in the proportion already given, and milled, answers well. In a large number of foundries the work is of such a character that new sand is seldom used alone for facing purposes, black sand being added in proportions varying from 25 to 75 per cent. The proportion of coal-dust also varies, and ranges from 5 to 15 per cent. The amount of coal-dust permissible varies with the nature and quality of the sand and the character of the casting: the heavier the casting the larger the amount of coal-dust that may be used. With light castings too much coal-dust gives a glazed and shiny surface, and with heavy castings a pitted or pock-marked surface full of veins. For castings over 3 inches in thickness McWilliam and Longmuir suggest the ratio of one part of coal-dust to 8 to 9 parts of sand. According to Sharp (*Modern Foundry Practice*) the following is the composition of a good facing sand:—

Black floor sand	10 parts.
New river sand	5 „
Coal-dust	1 „

With some classes of work coal-dust in the facing sand has an effect on the casting similar in appearance to that of cold-short working, which is especially noticeable at the teeth of small spur-wheels. This is obviated by omitting the coal-dust. (Sharp.)

For steel castings any of the red sands may be used, provided a suitable facing is dusted on. Floor sand strengthened by the addition of loam, and mixed and milled, is also employed. Sometimes coal-dust is added, and for certain work either beer-dregs or molasses. Only light castings, requiring little finish or surface, are made in green sand.

For brass casting the finest qualities of Belfast, Mansfield, and Birmingham cemetery sands are used for facing purposes. The sands must be drier than those used for iron casting, as the moulds have to be rammed harder, and also of a finer state of division in order the better to resist the searching or penetrating action of the metal. Usually no coal-dust is mixed with the facing sand, as it tends to produce pock marks and veined surfaces. Floor or bench sand, either alone or renewed by the addition of new sand, may be employed, but with ornamental work new sand is always used.

Dry Facing Sands.—Any of the sands which, after ramming, dry into a compact and coherent but porous mass may be used as facings for iron castings, and rock sand is especially suitable for this class of work. For cylinders and the teeth of spur wheels coke-dust is sometimes used. Either Mansfield, Erith, or Staffordshire sand may be used, provided the sand is mixed with horse-dung and milled. A dry facing sand wanting in bond, that is weak, may

be strengthened (tempered, as it is termed) by adding clay-water, core-gum, or flour.

The sands employed for steel castings have, owing to the high temperature at which the metal is poured, to be very refractory, and for this reason silica sands are generally employed. As such are generally deficient in bond, clay is added. Various compositions, "compos" as they are termed, are in use, and for the most part they consist of firebrick, silica-brick, old crucibles, etc., and various binding materials mixed and ground together. Harbord (*Metallurgy of Steel*) gives the following analysis as representing a steel-moulding composition:—

Silica	59·81	per cent.
Ferric oxide . .	5·42	,,
Alumina . . .	25·16	,,
Lime	1·14	,,
Magnesia . . .	0·75	,,
Potash and soda . .	3·00	,,
Loss on ignition . .	4·84	,,

Beckmann (*Giesserei-Zeitung*) gives the following as typical compos for steel moulds:—

(1) Firebrick, 12 parts; best clay, 3 parts; silver sand, 1½ parts; a little common sand being added to increase the porosity.

(2) Crucible shreds, 40 parts; best clay, 10 parts; quartz or silver sand, 30 parts; powdered coke, 10 parts.

(3) Firebrick, 12 parts; crucible shreds, 4 parts; best clay, 3 parts; graphite, 1½ parts.

(4) Quartz, 8 parts; best clay—which may also be replaced by syrup or treacle—10 parts; coke, 10 parts.

Black or Floor Sands.—It is obvious that the

composition of these sands must necessarily vary considerably, and is dependent on the facing sands originally used. McWilliam and Longmuir give the following as the composition of a black sand, from the floor of a foundry making light castings:—

Silica	78·5	per cent.
Ferric oxide .	6·00	„
Alumina . . .	4·75	„
Lime	0·30	„

The sand used in making the floor of a new foundry should be of an open nature and of moderate strength, and for the purpose the red and yellow sands of Worksop and Erith respectively are suitable.

Parting Sands.—An essential property of a parting sand is that it should not retain moisture. It should also be fine grained, uniform of texture, and free from chalky matter and salt. Burnt sand, red brick-dust, fresh sand, sea and river sand, and blast-furnace cinder, finely ground, are used.

Core Sands.—For core making a sand practically free from alumina and high in silica content, that is "sharp," such as rock sand, is used, the requisite bond being obtained by adding flour, core-gum, rosin, linseed oil, or other organic substances. Blast-furnace cinder, sea or river sand are sometimes mixed with fine, strong sand, and a little clay to make it adhesive. Clay added to give bond is objectionable, as the metal bakes the cores hard and renders their removal difficult.

Red or yellow sands, rendered open by means of horse-dung dried and riddled, and hardened with core-gum or rosin, are chiefly used for ordinary small

cores; and rock sand rendered open with horse-dung, and hardened by rosin for small intricate cores. Large cores are made from dry loam or dry green sand mixtures, to which sawdust or horse-dung and core-gum are added.

Loam.—The requirements of a loam mixture are, drying hard without undue contraction, and in this state it must admit of rubbing ("carding") without being friable; porous, soft and easy to work, adhere and attach itself to its supports and at the same time firm. There is a variety of loam mixtures used, such as Erith sand opened by horse-dung or cow-hair mixed with clay-water, or a mixture of close and sharp sands and clay-water added to obtain the requisite bond.

§ 9. OPENERS, BINDERS, AND FACINGS.

Openers.—Horse-dung, sawdust, and cow-hair are used to increase the porosity of the sand or loam, and are termed "openers." For small cores the dung is dried and sieved, and sieved only for dry loam or sand.

Binders are the substances added when it is required to obtain a hard surface, as distinct from that obtained by hard ramming, without increasing the fusibility of the sand. Core-gum, a glutinous substance obtained from potatoes and other starchy substances, and gluten itself, act as binders.

Facings.—Facings are used on the surfaces of all moulds to assist in peeling the sand from the casting, and they are either of a refractory nature, or are such as by the formation of a thin stratum of gas retard the searching or penetrating action of the molten

metal. They are used both in the dry and liquid states, and in a fine state of division, and are either siliceous or carbonaceous materials. The former include talc, soapstone, and silica-flour, and the latter coal, coke, charcoal, flour, peasemeal, and plumbago (mineral graphite), and blacking (mixtures of charcoal-dust, coal-dust, and fireclay; or plumbago and fireclay).

In green sand moulding the facing in the powdered state is applied to the surface of the mould through a porous linen bag, or stocking-foot, held over the surface to be coated, and the excess blown out by means of a bellows. Instead of blowing out, the facing may be smoothed on the surface of the mould with a trowel or "sleeker," or brushed with a camel-hair brush. In cases where the surface cannot be reached with the sleeker the pattern is returned to its place, lightly tapped to ensure uniform contact, and then withdrawn. This method is known as "printing."

Facings for Green Sand Moulds.

Type of casting.	Facing.
Iron, light .	Charcoal.
„ heavy .	Plumbago blacking, plumbago.
Brass, light .	Flour or peasemeal.
„ heavy .	Terra flake (floured silicate of magnesia), plumbago.
Steel . .	Floured silica.

In loam and dry sand work the facings are applied as a wash by means of a "swab," or brush, either

before the mould is dried or after, in the latter case, while the mould is still hot. For the purpose several substances are used, such as clay-wash, molasses water, core-gum, oil, beer, and beer grounds. All facings used in the liquid state come under the generic term "blacking." Plumbago gives better results with iron and brass than blackings. Sharp (*Modern Foundry Practice*) states that a blacking made by the Glasgow Patent Moulders' Blacking Co. may be used for all classes of work, including green sand, dry sand, and loam moulds, also moulds for steel, malleable, and gun-metal castings.

Steel moulds are faced either with nearly pure silica or carbon. "Compos" are also used, made from the following recipes (Beckmann):—

(1) Graphite 4 parts, firebrick 1, finest clay 1 part.

(2) Graphite 1 part, Dinas powder 1, the latter being mixed with dextrin before incorporation with the graphite.

(3) Siliceous sinter in dextrin solution.

(4) Graphite 12 parts, moulding compo-powder 4 parts; both in a finely ground state.

Analyses of Sands.[1]

	Black.	Mansfield Red Sand.	Kidderminster Red Sand.	S. Staff. Red Sand.	Glenboig Silica Sand.	Clyde Rock Sand.
Silica	78 5	83·40	83·69	85·52	88·90	85·32
Ferric oxide	6·0	7·47	6·26	5·47	7·43	7·10
Alumina	4·75	3·14	4·10	3·72	4·17	3·74
Lime	0·30	0·20	0·66	0·74	1·02	0·64
Magnesia	...	0·62	0·51	0·52	0·86	0·31

[1] McWilliam and Longmuir, *General Foundry Practice*.

	Yellow Moulding Sands[1] quarried in South of England.			Red Moulding Sands[1] quarried in Warsop, Notts.		
	Strong.	Medium.	Weak.	Strong.	Medium.	Weak.
Silica	80·50	83·10	88·30	78·70	84·90	85·30
Ferric oxide	3·20	2·70	2·59	2·23	2·34	2·57
Alumina	11·00	9·80	7·64	7·57	5·56	6·03
Lime	1·20	1·04	0·72	2·70	0·40	0·80
Magnesia	1·08	0·71	0·58	1·73	1·24	0·46
Loss on ignition	2·38	2·03	0·92	5·05	1·84	1·62

American Chemical Specification for Foundry Sands.[1]

	Light.	Medium.	Heavy.
Silica	82·21	85·85	88·40
Alumina	9·48	8·27	6·30
Iron oxide	4·25	2·32	2·00

§ 10.—FOUNDRY FURNACES.

The three principal types of furnaces employed in the foundry for the melting of iron and other metals and alloys are, the crucible or pot furnace, the reverberatory or "air" furnace, and the cupola.

The Crucible or Pot Furnace.—On account of its being the most expensive in fuel consumption, this

[1] S. B. Smith, *Journal Cleveland Institute of Engineers*, 1908, No. 2.

furnace is usually used only for the melting of iron on a small scale, such as in the production of malleable castings, and for other special purposes. For the melting of brass, Muntz's metal, German silver, etc., and the preparation of these alloys, it is, however, extensively used. In this type of furnace the draught is invariably obtained by means of a chimney or stack, the air indrawn being admitted under the

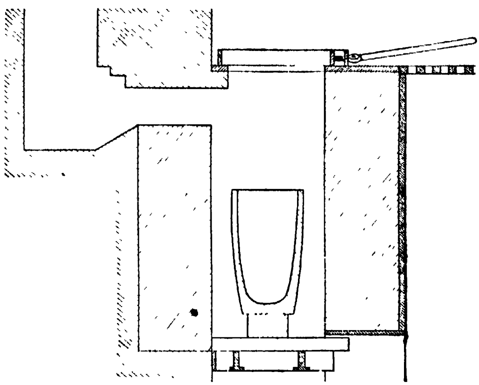

FIG. 1.—One-pot or crucible furnace.

fire bars. The proper construction of the furnace and flues is of considerable importance, as a slight difference in the arrangement will considerably affect the draught. Each hole should, if possible, have an independent chimney and flue, and failing this a series of holes leading to a chimney on a centre line, rather than to one at one end. Fig. 1 is the elevation of a one-pot or crucible furnace for malleable iron, brass, etc., with the top of the hole level with the

floor. The lining is of firebrick, and the draught is regulated by tilting the cover of the furnace more or less open at the top. Fireclay pots are used, and the charge for iron melting does not usually exceed 70 lbs. Crucibles for brass vary in capacity from 30 lbs. to 600 lbs.

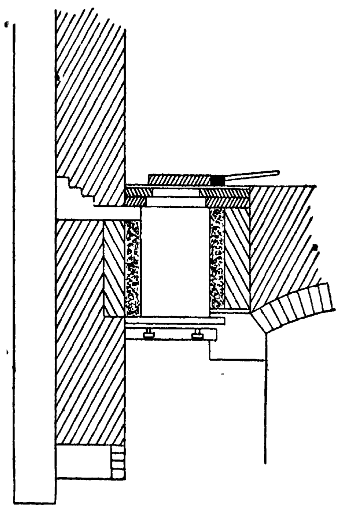

FIG. 2.—Two pot-hole furnace.

The two pot-hole furnace, shown in fig. 2, for steel smelting, consists of a rectangular chamber built in with 9 inch firebricks, and the hole, 3 feet deep and from 1½ to 2 feet square, is shaped by ramming ganister around a wooden core. The top of the hole is level with the floor, and covered with a square of firebrick. The draught is regulated by means of

loose bricks in the chimney under the level of the bars. The crucibles or pots are made of fireclay or of graphite or plumbago, and have a capacity of about 56 lbs. of metal.

The fuel[1] employed in heating crucible furnaces is a specially hard-burned coke, which should be as free from sulphur as possible, as if high, owing to the porosity of the crucible, the metal will invariably be found to have increased in sulphur contents.

The Reverberatory or Air Furnace.—When a

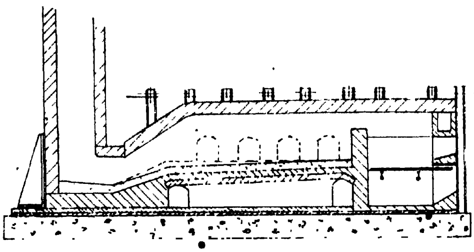

FIG. 3.—Reverberatory or Air Furnace.

large quantity of metal of a uniform quality is required, as for chilled rolls, iron for large malleable castings, ingots of yellow brass, etc., the air furnace is used. The furnace is generally of the reverberatory type with a double-arched roof, so that the roof dips very much in the centre, whereby the space in the melting part is reduced and the flame made to play over the surface of the metal, which probably tends to reduce oxidation of the metal. The bed, bridge, and roof are usually built of firebrick, and

[1] Crucible furnaces are also gas heated.

repaired with fireclay or ganister. The bed of the furnace slopes towards the tap-hole, and in some cases is formed of sand rammed on the brick. The fuel used is a non-clinkering coal, burning with a long flame. Natural draught is usually employed, and it is regulated by opening or closing the doors (which open outwards) fitted to the ash-pit. By adjusting the doors to regulate the air supply, an oxidising, neutral, or reducing flame may be obtained as required. The rate of melting is slow, and the fuel consumption high. With iron, the fuel consumption varies from 10 to 20 cwts. per ton of iron, and an average of $\frac{3}{4}$ cwt. of coal per cwt. of alloy.[1]

The Cupola.—In its simplest form a cupola may be described as consisting of a vertical cylindrical iron shell, lined with a single course of firebrick or other refractory material, resting on a cast-iron base plate, open at the upper end, with openings at a short distance from the bottom for the admission of the air necessary for combustion. About half way up is an opening, termed the "charging door," for the introduction or charging of the iron, fuel, etc. At the bottom there is a small hole ("tap-hole") for the drawing off of the molten metal, and opposite an arched opening—the breast—covered with a plate, by means of which access is gained to make the necessary repairs, to remove the ashes and unfused material. In front of the tap-hole is a spout or launder for conveying the molten metal to the casting ladle. Just above the breast-opening, but a little below the tuyère openings, is a slag-hole. The molten metal accumulates in the vertical space between the bottom

[1] McWilliam and Longmuir, *General Foundry Practice.*

end and the commencement of the openings for the admission of the air or blast, and this space is termed the "well" or "hearth." The iron plate forming the bottom is covered with refractory material —sand or ganister—rammed and shaped to slope towards the tap-hole.

There are several forms of cupola:—

(1) *Solid-bottom cupolas*, which are cheap, easy to work, and suitable for small outputs.

(2) *Drop-bottom cupolas* (fig. 4). —In this type the cupola is carried on short iron columns, and, instead of being provided with an opening in the side for the removal of the unfused material, the bottom is made in two halves, and hinged so as to hang down like a trap-door. In small cupolas the bottom doors are held in position by means of a bolt with a ring head, so that a hooked bar may be inserted for withdrawing the bolt. The bottom doors of a large cupola are supported by means of props between the foundation and the under sides of the doors. This form of cupola is suitable for large outputs, and has the advantage that whenever the cupola is thrown out

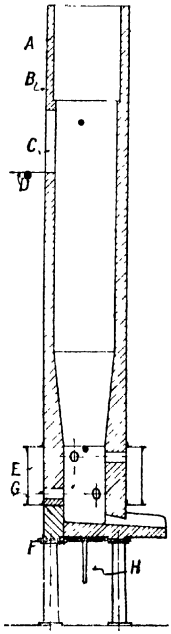

FIG. 4.—Section of drop-bottom cupola.

A, brickwork; B, iron shell, C, charging door, D, charging platform, E, air belt; G, tuyere; F, drop bottom; H, lever for working drop bottom

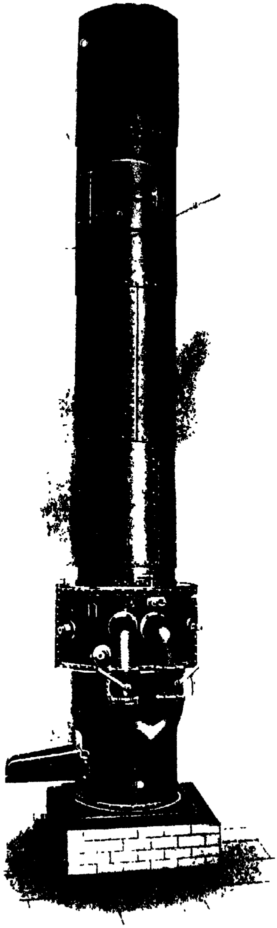

FIG. 5.—Thwaite's rapid cupola, without drop bottom and receiver.

of work the bottom is readily removed, and the cupola cleaned and repaired. Generally a drop-bottom cupola is provided with a fettling door opposite the spout.

(3) *Cupolas with receivers*, of which Thwaite's "Rapid" is a type. In this form the metal is received and accumulates in a separate receiver, and not, as in the two previous types, in the space between the bottom of the hearth and the tuyères. The receiver is usually made of a capacity to contain one half-hour's melt, and is lined with firebricks, and connected with the cupola by a brick-lined channel. A hot-air pipe between the cupola and the receiver supplies hot air to the latter to prevent chilling of the iron. The chief use of a receiver is to facilitate the mixing of the iron, and thereby promote uniformity of quality.

Of the three types, the solid-bottom is the cheapest in first cost, and cost of up-keep, lining, etc., is easiest to work, requires the least amount of fettling, and, compared with a cupola with a receiver, will, with the same weight of fuel, produce a hotter iron, there being less brick-work to heat up. The disadvantage of a solid-bottom cupola is that when more iron is charged than is required it is usually melted out, as this is the easiest way, and thus coke in excess of that actually required is burnt and lost. In a drop-bottom cupola, the iron and unconsumed coke would in such a case be dropped out on to the floor, and separated. The amount of coke required to form the bed is greater with solid and drop-bottom cupolas than with cupolas of the receiver type, due to the former requiring a greater distance between

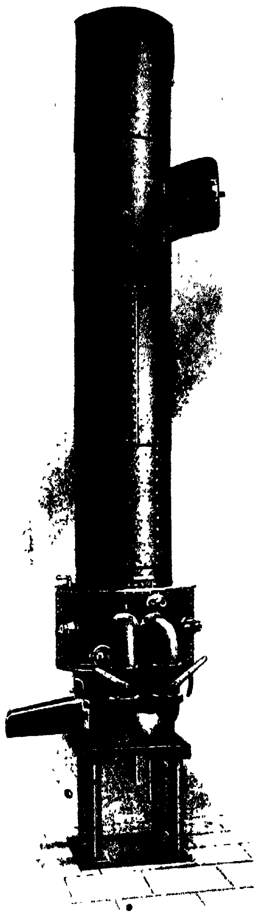

FIG. 6.—Thwaite's rapid cupola, mounted on drop bottom, and without receiver.

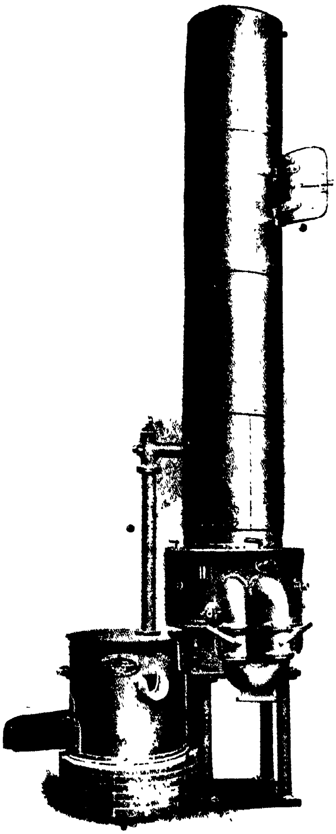

FIG. 7.—Thwaite's improved rapid cupola, with drop bottom and receiver

the bottom of the hearth and tuyères, to allow of a body of metal being collected. Notwithstanding this fact, cupolas with receivers are not so economical in fuel consumption, and require more fettling than the other types.

There are several methods of supplying the air to a cupola:—

(1) In ordinary practice the air enters the cupola under pressure, through two or more tuyères, which may be in one row or more, placed in a horizontal plane around the sides of the cupola just above the hearth. The number of tuyères employed varies, and when two are used they are usually supplied direct from the blast main, but where a number of tuyères is used an air belt is fitted to the cupola, and the tuyères are placed in rows, one above the other, the openings being "staggered" to allow of equal distribution of the blast.

The air or blast is supplied by a fan, or more usually a Root's blower, as illustrated in fig. 8.

(2) By suction, in which the air is aspirated by means of a steam jet arranged in a tube or chimney connected with the cupola. Air is admitted to the cupola through openings round the melting zone.

(3) Air is supplied to the centre of the charge. This is accomplished by means of an air pipe passing up through the bottom.

The chief essential of a cupola is, that it melts hot and fast with a minimum of fuel. The height and area of the stack or chimney of a cupola should be such that the flame and gases are drawn away from the charging door; and the distance between the tuyères and the charging door should be sufficient to

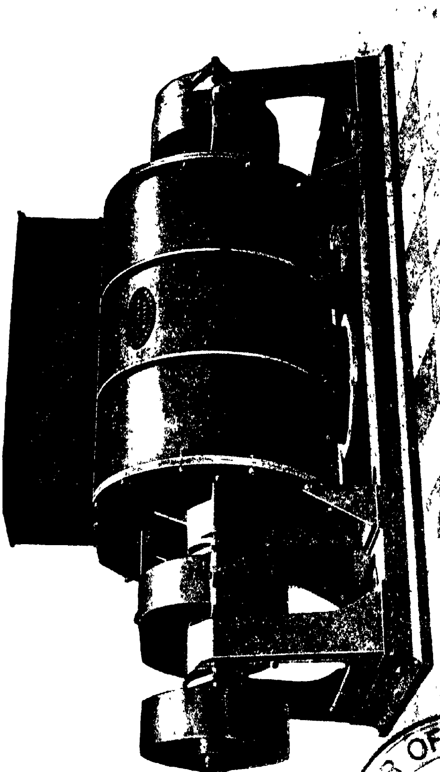

FIG. 8.—Thwaite's improved Root's blower. No. 7 size.

allow of the ascending flame, and the products of combustion, imparting their heat to the descending charge. The usual distance of the charging door from the bottom of the cupola is twelve feet. The lining of cupolas is generally contracted in the neighbourhood of the tuyères, to allow of the blast penetrating right to the centre of the cupola, and, to a lesser extent, to reduce the amount of coke required to form the bed. The bed of coke should extend to at least 12 inches above the tuyères. As regards the number of tuyères, one row, provided they are of sufficient capacity (by capacity is meant the total area of the openings for the admission of the air to the interior of the cupola), will yield hot iron, but more slowly than two rows, which melt hot and fast. With two rows of tuyères more perfect combustion is obtained, the second row supplying the air for the combustion of the carbon monoxide formed at the lower tuyères to carbon dioxide. Three rows also melt hot and fast, but the upper row cuts the lining and demands a deep coke bed Keep gives the tuyère area as not less than one-ninth the area of the cupola; McWilliam and Longmuir give the area as one-tenth the cross-section of the cupola in small, and one-seventh in large cupolas. The size of the hearth is determined by the distance between the lower tuyères, whether single or double rows, and the bottom of the cupola, and is dependent on the class and weight of castings to be produced, the duration of the cast, and also whether a receiver is used to collect the molten metal or otherwise. If the distance is too little, there arises the danger of slag, and perhaps iron, getting into the tuyères, and also in the melting together of iron and

scrap there is a danger of these not mixing, and separate strata of each being obtained. For cupolas with a receiver a distance of 4 inches is sufficient, while with the other types any distance less than 12 inches above the bottom is only suitable for hand ladle work. The slag-hole, with which every cupola should be provided, is placed just below the tuyères, opposite the tap-hole. The following are the dimensions of a standard drop-bottom cupola. 44 inches diameter, 12 feet from sole to charging door; 6 tuyères, 6 inches in diameter, 18 inches from the bottom. (McWilliam and Longmuir).

For raising the materials of the charge to the charging platform or stage, which is placed at a convenient height below the charging door, hoists or lifts are employed.

Lining the cupola.—The cupola is generally lined with a single course of firebricks,[1] frequently only to or just above the charging door, but in order the better to withstand a long or continuous run a lining of ganister may be added. The firebricks are set in thin fireclay to allow of their being laid tightly against each other, and built in sections of 2 to 3 feet or more, each section being supported on angle-irons riveted to the inside of the casing or shell. To allow of contraction and expansion, a space of about ¾ inch is left between the shell and the firebrick lining, which space may be loosely filled with parting sand. When a ganister lining is added, the brick lining is dried and the ganister rammed round a short wooden model formed of the size and shape of the inside of the cupola, which, as each portion is completed, is raised,

[1] With large cupolas two courses of firebricks may be used.

and the ramming continued until the charging door is reached. This lining is afterwards dried.

In putting in the lining, the change from the small to the large diameter in the neighbourhood of the tuyères must be gradual, and not sudden, or otherwise a shelf or ledge will result upon which the descending coke is likely to hang.

Generally the lining above the charging door will last as long as the shell, and the portion from this point to the melting zone, which is worn away more by the abrasive action of the charge than by the cutting action of the heat, will, under ordinary circumstances, last several years. The lining at the melting zone, and also that at the boshes, will require renewing every few months. The portion below the tuyères, in contact with the liquid iron and slag, should have twice the life of that at the melting zone.

Pressure of blast.—The pressure of the blast varies up to 18 ozs. per square inch, but the pressure usually used is 10 ozs. per square inch (equal to 21-inch column on a water-gauge). As the diameter of the cupola increases so should also the pressure of the blast. If the pressure is too low ("soft") it will not penetrate to the centre of the cupola, and although under this condition iron may be melted hot, it will be at the cost of speed and of time, and loss of combustible gas, therefore waste of fuel. With too great a pressure ("cutting") the rapid rush of gas may cause the ejection of solid material, and the iron will be chilled, and the atmosphere becomes so strongly oxidising that not only will an undue proportion of silicon be oxidised, but the iron may also be oxidised, and pass

into the slag. The quantity of air used should be only slightly in excess of that actually required.

Fuel.—The fuel most commonly used in the cupola is coke. It should be well burned, bright, dense, hard, and sufficiently strong to carry the weight of the metal charged upon it without crumbling. It should contain not less than 88 per cent of fixed carbon, and be low in ash contents. As the iron in melting in the cupola is in direct contact with the fuel, the coke must be low in sulphur contents—not over 1 per cent—otherwise a sulphury and hard metal will result. Although under normal conditions of working the metal does not take up phosphorus, nevertheless the coke should be as free as possible from this constituent.

Limestone.—The limestone used to combine with the sand on the pig-iron and the ash of the fuel, to produce a fusible slag, should be as pure as possible, and contain not over 2½ per cent. silica, and not less than 53 per cent. of lime. The quantity generally used is from 3 to 5 lbs. per cwt. of coke.

Bohemian flux, which is claimed to be superior to limestone as a flux, is practically a mixture of one-third fluor-spar and two-thirds limestone.

Putting in the Bottom. Making the Tap-hole. Lighting up.—In preparing the cupola for a heat, the lining is chipped out, projecting lumps of slag removed, and the worn parts repaired with fireclay or preferably ganister. Should the cupola be of a drop-bottom type, the bottom doors are placed and fixed in position, after which the bottom is made. For this purpose the foundry floor or black sand is passed through a ¼-inch riddle, damped sufficiently to cohere

when pressed together, and spread over the bottom plate or doors, which have previously been brushed over with clay-water, evenly rammed, and, with a drop-bottom cupola, the sand tucked well in the spaces between the lining and the doors. At the tap-hole the bottom is brought level with the lining of the spout or runner by which the molten metal passes from the tap-hole to the ladle, and from here made to slope, about $\frac{1}{2}$ inch per foot upwards, towards the back so as to completely drain the metal towards the tap-hole. (Too great a slope will cause too much pressure on the clay stopping of the tap-hole.) Care must be taken not to have the bottom too wet or rammed too hard, or else the molten metal will scab or blister the sand, and let the metal out. When complete, the bottom may be brushed over with clay-water or blackwash.

To make the tap-hole, in the opening left for the purpose in the lining (and iron shell) of the cupola is placed a tapered bar of iron or wood of the diameter required in the tap-hole, and the intervening space between the bar and the lining made up with sand or a mixture of clay and sand carefully and tightly rammed. When made the bar is withdrawn.

The spout or launder is lined with sand or ganister to protect it from the action of the molten metal.

The tap-hole may either be kept open throughout the heat, or closed and opened again when sufficient metal has accumulated. It is closed with a mixture of two-thirds clay and one-third sand, moulded into the form of a cone, which is placed on the end of an iron bar (termed the "bod" stick), and rammed into

the tap-hole. Should the cupola be provided with a slag-hole it is made up and closed in a similar way. Both the tap-hole and the slag-hole are opened out when required by means of a tapping bar.

To light up the cupola, spread shavings over the bottom, and pile them up around the tuyères. Then on the shavings place dry wood, and on the top of the wood make the coke bed.[1] (Coal may also be used in lighting up, but the quantity should be kept as small as possible, as on account of the sulphur it contains there is the risk of hard, that is sulphury, iron being obtained.) Light the shavings at the tuyères and at the tap-hole, and keep both of these open to admit the air required for combustion. When the coke is well alight to the level of the tuyères the charging of the pig-iron is commenced.

Charging the Cupola.—In charging the cupola a system should be followed, and the materials should not be thrown in, in a haphazard way. Level charging with a level descent of the charge should be aimed at, as these go a long way towards satisfactory melting. The several materials making up the charge should be weighed, and in charging, a thin layer of scrap should be placed uniformly on the top of the bed of coke, to prevent the weight of the pig-iron crushing the coke. The pig-iron is charged on the top of the scrap, broken into four pieces if the cupola is 30 inches diameter, and six to eight pieces if smaller. On the top of the pig, scrap is again charged and evenly distributed over the whole area. Above this

[1] In order to obtain the necessary height, with a minimum of weight, for making the bed large pieces of coke should be used.

the next bed of coke is placed, and also the limestone required for fluxing the sand on the pig-iron, etc. Charging is continued in the order described until the cupola is full to the charging door. In charging it is a good plan to throw the iron well to the centre of the cupola, and the coke more towards the sides —the iron lying, as it were, in a shallow basin of coke, the sides and bottom of which are of equal thickness. It is important, however, that the previous iron charge and the one being added be separated and supported by a bed of coke. The amount of coke put on between the several charges of iron to form the bed should be such as to keep the bed level with the top of the melting zone, and only sufficient to replace the coke already consumed in melting the iron just liquefied. If the quantity used is too great, partial stoppage of melting may result until the excess of coke has burned sufficiently to bring down a further supply of iron to the melting zone, and thus cause a waste of fuel. In other words, the quantity of coke used to form the bed between each charge of iron should be such as to exactly fill the space vacated by the coke used in melting the previous charge of iron. Irrespective of the quantity of coke used no actual melting of the iron takes place until the metal reaches the melting zone. Where the same cupola is used to melt charges of different character, a deeper bed of coke should be added to separate the charge being added from the one below. When the cupola is filled to the charging door, the blast may be put on, and, although some founders hold that this should not be done for one or two hours after the charging is complete,

hotter iron is obtained by so doing. Before putting on the blast, sand is placed in front of the breast-plate, which is then wedged in position between snugs on the casing.

Under good conditions of melting there is no continuous flaming up through each topmost charge put on, and if such takes place it points to the coke bed being too large. It may also be brought about by a deficiency or bad distribution of blast, or a too short cupola, or too great a pressure or volume of air, or the charge consisting of too large pieces, and should be avoided as it is a waste of heat, and is combustion which should have taken place lower down. There may be a flame in the chimney stack immediately above the charging door, in fact there usually is such a flame. This flame is the burning of the carbon monoxide, probably from the incandescent fuel just above the melting zone, and is characterised by being of a bluish-pink colour, and the flame clinging to every little projection and ledge in the chimney stack. When the flame in the chimney is of this bluish-pink tinge, the blue predominating, the flame clinging to the chimney wall, now and again running down and burning at an opening in the charge in a ragged sort of way, then good melting is being done. The pinker the flame, the greater the heat of the escaping gases, and, therefore, a waste of fuel. Under good working conditions the temperature of the escaping gases does not exceed 350–400° C. A flame of whitish-yellow colour, extending through the charge and up into the chimney, and often out at the top of the chimney, and without the ragged appearance of the proper

flame, indicates that too little air is being blown into the cupola. Such a flame may be seen in a cupola with proper blast any time when a tuyère is opened, thus temporarily reducing the blast pressure. This flame is also an indication of scaffolding or other obstructions to the free passage of the blast, and when it appears and the blast-gauge indicates a rise of pressure, then it is well to see if scaffolding has begun.

No rule can be given for the amount of coke to be used to form the coke bed, neither can one be laid down for the subsequent charges of iron and coke. Both these vary, and can only be determined by actual trial. The fuel required to melt a charge consisting of small pieces is less than that of one made up of large pieces. In the former case, owing to a greater cooling surface being presented the gases leaving the cupola are more cooled, while in the latter case, the larger spaces between the pieces allow of the more rapid escape of the gases. It is, however, advisable to err on the right side, and to start with a comparatively high coke bed, and gradually decreasing the weight until the right amount is found. With too low a bed, the iron is dull and without life, while if the bed is too high, the iron melts slowly. So, too, with the charges of iron, it is advisable to commence with comparatively light charges of iron to heavy coke, and to gradually increase the weight of iron until the best conditions are found. As an example of charging, the following is taken from a paper by R. Buchanan[1]:

[1] *Staffordshire Iron and Steel Institute Journal*, 1901.

Inside diameter of cupola 36 inches, contracted to 19 inches at the bottom. Height, bottom plate to charging door 15 feet. Two rows of tuyères of 78 square inches total area. Melts 4 tons per hour. Cupola full to charging door when 50 cwts. of iron in. Blast-pressure 8 to 10 ozs., and 24 to 28 lbs. of limestone put on top of each charge of coke.

System of Charging.

1. Bed of coke	5 cwts.		7. Coke	$1\frac{1}{2}$	cwts.
2. Iron	10	,,	8. Iron	10	,,
3. Coke	$1\frac{1}{2}$	,,	9. Coke	$1\frac{1}{2}$	,,
4. Iron	10	,,	10. Iron	10	,,
5. Coke	$1\frac{1}{2}$	,,	11. Coke	1	,,
6. Iron	10	,,	12. Iron	10	,,

In melting different grades of iron, and all important work, the metal should be remelted two or three times before the final casting is made, the iron from the first melt being cast into pigs, broken up, and recharged.

Scaffolding—A cupola is said to scaffold when the charges of coke and iron do not follow down the previous charges of coke and iron as they burn and melt respectively. With such a condition there is usually an empty space in front of the tuyères, and a roof of solidified iron and slag, which may or may not extend over the whole cupola. Scaffolding may be caused by:—

(1) Inferior coke, that is high in ash, low in fixed carbon content, or weak and friable.

(2) An insufficiency of flux or coke.

on the surface of the iron and the mouth of the ladle covered with a plate to prevent undue chilling. Provided it is not allowed to get too cold, standing of the iron in a ladle before pouring has a good effect, as thereby time is allowed for the absorbed gases to escape, the manganese and silicon react upon the dissolved and mechanically mixed oxides, and the manganese combine with the sulphur forming manganese sulphide which enters the slag.

With the object of eliminating the dissolved gases, and thereby obtaining sounder castings, lead, zinc, tin, sodium, magnesium, aluminium, titanium, and ferric compounds (ferro-silicon, ferro-manganese) are sometimes added to the iron in the ladle. The first three act mechanically, and the others chemically, by reducing the oxides. As aluminium promotes the separation of the carbon in the graphitic state, it cannot be used with an iron low in silicon for strong castings.

Ladles.—The ladles used to collect the molten iron as it is tapped from the cupola, and to pour it into the moulds, are made of wrought iron, or mild steel, and lined with sand or other refractory material, and dried and heated previous to use. They vary in size according to the class of work in hand, from the small hand-ladle holding pounds, to those of several tons capacity.

Pouring or Casting Temperature.—To obtain good castings it is most essential that the metal be poured at a correct temperature. This varies not only with the character of the iron, but also with the size of the casting, and, as a general rule, the smaller

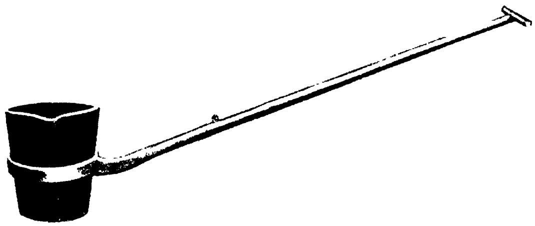

FIG. 9.—Hand shank ladle.

FIG. 10.—Double hand shank ladle.

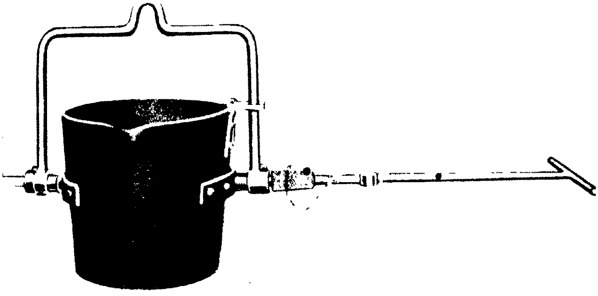

FIG. 11.—Crane ladle.

the casting and the more intricate the pattern the higher must be the temperature of pouring. If the temperature is too low the mould may not be filled,

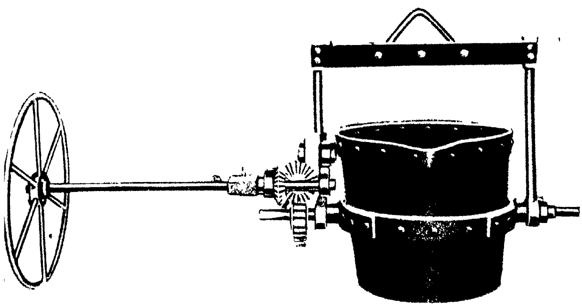

FIG. 12.—Geared crane ladle.

while, on the other hand, if it is too high blowholes, rough surfaces, and want of strength in the casting may result.

The metal should be poured in a steady stream, and sufficiently rapid to keep the basin, runner, and gate full.

§ 11.—MIXING.

Of the several problems which are met with in foundry practice, the proper selection and mixing of the iron is one of the most difficult and important, as on it depends the cost and the properties of the resulting castings. There are several factors which have to be kept in view, and which either singly or collectively have to be considered: (1) The class of

casting to be produced, whether heavy or light. As regards this, an iron (soft) which would give a satisfactory light casting would be wholly unsuitable for a heavy casting, and *vice versa*. (2) The cost of the iron, and the cost of production as compared with the price obtained for the casting. (3) The iron obtainable at hand. Frequently the founder is considerably handicapped by being so situated as to have no choice but to use local iron, which, although not the one he would desire, is, on account of the price, the only one permissible. (4) The chemical and physical properties of the castings. It may be that castings have to be made which have to meet both chemical and physical specifications. (5) The changes that take place in remelting the iron. (6) The influence of the several elements, silicon, etc., on the metal

As already stated, the fracture is the most common guide in selecting or grading the iron, and, where a man is constantly using iron from one or more and the same sources, this is a very good criterion of the properties, and excellent results are obtained. Owing, however, to several causes—such as irregular working of the blast furnace, fast driving, the rate of cooling, the experience and judgment of the man grading—there is frequently very little connection between the fracture and the properties of the iron, and an iron which to all appearances is soft, is in reality hard, and *vice versa*. Selecting by fracture is, therefore, frequently the cause of unsatisfactory castings, and the founder wonders why, as previously with the same make of iron and the same mixture, he has obtained good results. Although selection or grading by analysis (which to all intents is grading by the

silicon content) is on the whole more satisfactory, it must be borne in mind that it is not a panacea for all the ills, as unless used with intelligence coupled with a thorough practical knowledge, the results obtained may be, and frequently are, unsatisfactory. No doubt the lack of practical knowledge is one of the reasons why the chemist is looked upon by the foundry man with more or less distrust, and a necessary evil, and his duties regulated to that of an analyst only, whose sole work consists in seeing that the several materials entering the foundry are up to the usual standard. It is essential that the foundry chemist be not only a competent analyst but also a practical metallurgist, to be of any real value and help to the iron founder.

For various reasons—(1) Differences in grading; what in one district may be classed as a No. 2 iron may in another be graded as a No. 1. (2) Differences in opinion as what iron or mixture of iron is most suitable for the various types of castings. Almost every founder has his own ideas as regards this, and his own particular mixture. (3) The iron obtainable in one district being different to that of another,—no formulæ can be given for iron or mixtures suitable for the various types of castings which can be applicable in all cases.

The following are some mixtures, and the purposes for which they are used:—

Fly Wheel.		Intermediate Pressure Cylinder.	
No. 1. Hematite .	20 %	No. 1. Hematite .	25 %
No. 4. " .	80 "	No. 4. " .	25 "
		No. 3. Cleveland	25 "
		Scrap . . .	25 "

Steam Pipe.

No. 1. Hematite	20 %
No. 3. Cleveland	30 ,,
Scrap and returns	50 ,,

Small Bed-plate.

No. 1. Hematite	6 %
No. 4. ,,	29 ,,
No. 3. Cleveland	65 ,,

Propeller.

No. 1. Hematite	14 %
No. 4. ,,	34½ ,,
Scrap . .	40 ,,
Steel . .	11½ ,,

Low-Pressure Cylinder.

No. 1. Hematite	18¾ %
No. 4. ,,	27¼ ,,
No. 3. Cleveland	27 ,,
Scrap . .	27 ,,

High-Pressure Cylinder.

No. 1. Hematite	24½ %
No. 4. ,,	23¼ ,,
No. 3. Cleveland	23¼ ,,
Scrap . .	29 ,,

High-Pressure Valves, etc.[1]

Stanton IV. .	40 %
Gartsherrie III. .	20 ,,
Warner, C.B.R. IV.	6½ ,,
Foundry scrap .	33½ ,,

Heavy Marine Cylinders.[1]

Staff. Cold Blast I.	10 %
West Coast Hem. III.	20 ,,
Coltness III. . .	20 ,,
Good engine scrap	50 ,,

	Cylinders.[2] (Marine.)	Condensers.[2] (Marine.)	Bed-plates[2] (Marine), Pumps, and other castings.
Selected old or re-melted metal	50 %	50 %	50 %
Scotch . . .	20 ,,	15 ,,	...
Cleveland, 3 G.M.B .	30 ,,	20 ,,	50 ,,
Hematite . . .	...	15 ,,	...

[1] McWilliam and Longmuir.

[2] Dalrymple, *Cleveland Institute of Engineers*, 1908, No. 5.

	Steam Cylinders, and Slide Valves [1] (Clyde district).	Columns and Condensers [1] (Clyde district).
Gartsherrie No. 3 .	Equal parts	Equal parts
Summerlee " .		
Coltness " .	...	

	Hydraulic Cylinders.	Spur-wheels, Pulleys.[1]
Nos. 3 and 4 Middlesbrough brands	Alone	Equal parts
Coltness Nos. 1 or 3		

Locomotive and other Cylinders	Cwts.	Qrs.	Piston Rings.	Cwts.
Lilleshall . .	5	0	Lilleshall . .	4
Madeley Wood, cold blast .	3	3	Madeley Wood .	4
Glazebrook, cold blast .	2	2	...	
Philip Williams, cold blast .	2	2	...	
Hematite .	2	2	...	
Cylinder scrap .	10	0	...	

	Analysis of Dynamo Casting.[2]	Analysis of Soft and Light Machinery and Stove Plates."
Silicon . .	3·19 %	3·75, 3·70, 3·65, 3·60 %
Sulphur . .	·075 "	Sulphur, phosphorus,
Phosphorus . .	·89 "	and manganese being
Manganese . .	·35 "	fairly constant.
Graphitic Carbon	2·89 "	...
Combined "	·06 "	...
Total "	2·95 "	3·00, 3·25, 3·50, 3·75 %

[1] Sharp, *Modern Foundry Practice.*
[2] West, *Metallurgy of Cast-Iron.*

Approximate Analysis for Chilled Rolls Mixture.[1]

Diameter of Rolls.	Silicon.	Sulphur.	Phosphorus.	Manganese.	Total Carbon.
Inches.	%	%	%	%	%
8 to 10	1·00	·01 to ·06	·20 to ·80	·15 to 1·5	2·6 to 3·25
12 to 14	·8	...		...	...
16 to 18	·7	...	...		
20 to 22	·6	...			
21 to 26	·5	...	...	...	...

§ 12.—MIXING BY ANALYSES.

With a knowledge of the chemical composition, and of the weights of the different irons and the scrap that go to make up a mixture, it is possible by means of an arithmetical calculation to find the composition of the mixture, and also, if the changes which the metal suffers in melting are known, of the resulting casting.

Problem 1.—Given the weights and the chemical composition of the pig-iron and scrap of which the mixture is made up, find the composition of the mixture, and, after allowing for the changes in composition in melting, of the resulting casting.

Rule.—Multiply each weight of pig-iron and scrap by the percentage of each element it contains, and divide the sum of each by the total weight of the mixture. The results are the percentages of the several elements in the mixture and, after allowing for the changes during melting, of the casting.

As an example we will take a 10-cwt. mixture,

[1] West, *Metallurgy of Cast-Iron.*

made up of 7·33 cwts. of pig-iron A, and 2·67 cwts. of pig-iron B, considering the silicon only. The analyses of the pig-irons are as follow :—

Pig-iron.	Silicon	Sulphur.	Phosphorus.	Manganese.
	%	%	%	%
A . .	2·50	·05	·70	·50
B . .	1·75	·08	·73	·40

Percentage weight of silicon in A pig-iron . } $= 7·33 \times 2·50 = 18·32$ cwts.
Percentage weight of silicon in B pig-iron . } $= 2·67 \times 1·75 = 4·67$ „
Total . 22·99 „

Then percentage of silicon in mixture $= \dfrac{22·99}{10}$ $= 2·299$ per cent., say 2·30 per cent.

The loss of silicon in melting was found to be ·30 per cent., and the calculated silicon in the resulting casting would, therefore, be $2·30 - ·30 = 2·00$ per cent.

The other elements are calculated in the same way, and the following shows how the mixture should be tabulated and the calculated composition obtained :—

Iron.	Cwts.	Si.	Si. cwts	S.	S. cwts	P.	P. cwts.	Mn	Mn. cwts.
		%	%	%	%	%	%	%	%
A . .	7·33	2·5	18·32	·05	·366	·70	5·13	·50	3·66
B . .	2·67	1·75	4·67	·08	·213	·73	1·95	·40	1·66
Total	10·00 cwts.		22·99		·579		7·08		4·72

The above is the cwts. per cent. of each of the elements in the mixture, but as the charge is 10 cwts., the cwts. per cent. of each element divided by 10 will give the calculated composition of the mixture, and the mixture will contain:—

Silicon	2·30	per cent.
Sulphur . . .	·058	,, ,,
Phosphorus . . .	·708	,, ,,
Manganese . . .	·472	,, ,,

Previous practice showed that in melting in the cupola the metal lost ·30 per cent of silicon, the sulphur was increased by 0·028 per cent., the phosphorus remained practically the same, and the manganese was decreased by ·20 per cent. Based on these figures the calculated composition of the resulting casting would be:—

		Calculated Composition.	
		Before melting.	After melting.
Silicon	% .	2·30	2·30 − ·30 = 2·00 %
Sulphur	,, .	·058	·058 + ·028 = ·086 ,,
Phosphorus	,, .	·708	·708 ,,
Manganese	,, .	·472	·472 − ·20 = ·272 ,,

Problem 2.—Assume that the exact reverse of No. 1 is required, viz. that the analysis of the pig-iron is given, and a casting of a specified composition is required. The pig-iron A and B are used, and the silicon in the finished casting is to be 2·00 per cent. To this must be added the silicon lost in melting, viz. ·30 per cent., so that 2·30 is the silicon to be aimed at in the mixture.

On studying the analyses of the pig-irons, in regard to their relative positions to the amount of silicon

required in the mixture, we find that A iron is $2·50 - 1·75 = ·75$ higher in silicon than B iron, and B iron is $2·30 - 1·75 = ·55$ lower in silicon than that required in the mixture. From this it will be seen that, the weight of A iron multiplied by its height in silicon above iron B must equal the weight of the mixture multiplied by its height in silicon above the iron B. Thus in a 10-cwt. mixture:

$$\text{Weight of the A iron} \times ·75 = 10 \text{ cwts.} \times ·55$$
$$·75 = 5·5$$

and weight of A iron in 10-cwt. mixture $\frac{5·5}{·75} = 7·33$ cwts.

$$\text{Weight of B iron} = 10·00 - 7·33 = \quad 1·67 \text{ cwts.}$$

On checking this charge as in problem 1, it will be found that the silicon comes to 2·30 per cent. in the mixture.

Problem 3.—Using 20 per cent. scrap, containing 2·00 per cent. silicon, and the same pig-iron as in the previous examples, find the weights of A and B respectively required in a 10-cwt. mixture to give 2·30 per cent. silicon in the mixture.

10 cwts. at 2·30 per cent. silicon will require $10 \times 2·33 = 23$ cwts. per cent. of silicon in the mixture, but 2 cwts. of scrap at 2·00 per cent. silicon will furnish 4 cwts. of silicon to the charge, leaving $23 - 4 = 19$ cwts. silicon to be added by the pig-irons. This equals an average of $\frac{19}{8} = 2·37$ silicon.

Iron A is ·75 higher in silicon than iron B, and iron B is $2·37 - 1·75 = ·62$ lower in silicon than the average, viz. 2·37, silicon to be aimed at.

Then weight of A iron $\times \cdot 75 = 8$ cwts. $\times \cdot 62$
$\cdot 75 = 4 \cdot 96$

and weight of A iron $= \frac{4 \cdot 96}{\cdot 75} = 6 \cdot 61$ cwts.

Weight of B iron $= 8 \cdot 00 - 6 \cdot 61 = 1 \cdot 39$ cwts.

The charge would, therefore, be made up of :—

Scrap	2	cwts
A iron . . .	6·61	,,
B iron	1·39	,,
	10·00	cwts.

§ 13.—FOUNDRY TOOLS.

The tools required for moulding comprise :—

Moulding Boxes or Flasks (figs. 13 and 14) are essentially frames for holding the sand in which the casting is moulded, and are made either of wood or cast iron, preferably the latter. The simplest form of moulding box consists of a bottom part or drag as it is termed, and a top part or cope, the latter with or without cross bars. They vary considerably in shape—square, rectangular, or round—and size, according to the class of work they are used for, and floor moulding boxes are of larger dimensions than those used for bench work. The cross bars of the cope run from side to side set at a distance of $4\frac{1}{2}$ inches apart, and are of such a depth that the lower edges, which are tapered and shaped to suit the contour or sectional shape of the casting, do not come to within one inch of the pattern being moulded. They may be cast as part and parcel of the cope, or grooves or slides cast in the sides of the flask into which the cross bars

slide: in this case the bars may be wood. When in use removable cross bars are held in position by means of wedges or bolts Where the mould is equally divided between the cope and the drag, or both are turned over or lifted, the cross bars of the drag are similar to those of the cope; in other cases they are placed flatwise. Small boxes and boxes without cross bars are grooved lengthwise in the sides parallel to the parting to help hold the sand.

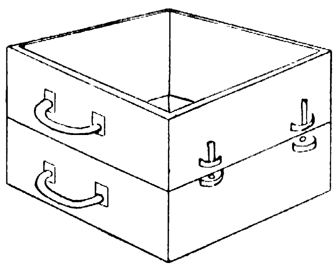

FIG. 13.—Moulding box or flask.

In order that the top part of the flask may lie evenly on the bottom part, the faces are planed and levelled, and to maintain the parts in a relative position one part, usually the drag, is provided with projecting pins, which correspond with guiding holes, slots, or grooves in the cope to pass over the pins. (In floor moulding frequently the cope has only projecting lugs against which stakes are driven to hold it in position.) For this purpose plain lugs, two, three, or more, are cast on the sides of the flasks about ¼ inch below the level of the joint or parting—that is the line of contact between the cope and drag—one set being

drilled to take the pin, and the other with holes to pass over the pins. The style of pin employed varies, being in some instances simply lengths of rod iron riveted into the lug of the drag. A more satisfactory method of fixing the pin is to reduce and tap the end to take a nut. In others a slot is cut through the guiding pin through which wedged-shaped cotters are passed. Hinged pins with cotter holes and screwed ends are also used.

For lifting and turning purposes, the flasks are

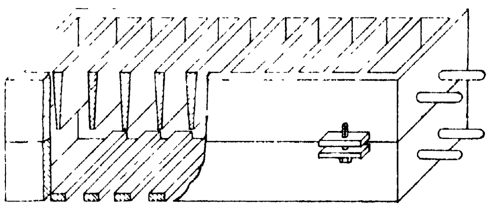

FIG. 14.—Moulding box or flask.

provided with handles, which may be either of the type, fig. 14, forming part and parcel of the flasks, or of wrought iron bent to shape, cast into the sides of the flasks, with bosses for strengthening. With large boxes, swivels or trunions with collar ends are cast in the middle of the ends of the boxes, or mid parts.

Middle parts are frames interposed between the cope and drag used to increase the depth. They are not provided with bars.

Snap flasks are moulding boxes hinged at one corner, and a locking arrangement at the corner diagonally opposite. When the mould is complete and previous to casting, the frame is removed.

Sometimes the boxes are hinged, and the top part (cope) instead of being lifted off, is turned up to allow of the withdrawal of the pattern and the finishing of the mould.

Turning-over Board is a board of the same outside dimensions as the bottom part of the moulding box being used. In making the mould the bottom part of the moulding box is placed upon it.

Bottom Board is similar to a turning-over board, and is used to prevent the sand falling out in turning over a mould.

Vent Rods.—These vary in size from the thickness of a knitting needle up, and are used for forming passages in the sand to allow of the escape of the air and gases generated on pouring a mould.

Sleekers are employed for smoothing over the surface of the sand and sleeking on blacking, in places not within reach of the trowel or cleaner. There are several varieties used for different classes of work (fig. 15).

Trowels (fig. 16) are the moulder's most indispensable tools. The handles are of ball form, and of wood.

Gaggers or lifters are used for supporting or strengthening the sand when the cross bars are insufficient for the purpose, and for tying sand together. They vary in size, and are made by bending an iron rod at an angle, so that one end will rest on the cross-bars of the box, and the other carry the sand.

Gate Cutters and Gate Knives are shown in fig. 17, *A* and *B* respectively.

Runner Pegs are cylindrical, tapered pieces of wood, varying in size, and are used for making the runner (fig. 18).

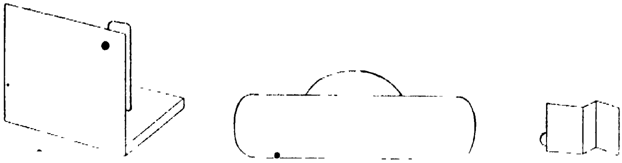

FIG. 15.—Sleekers.

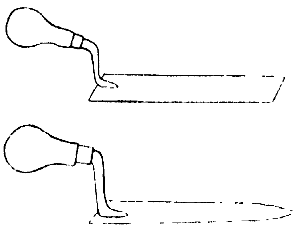

FIG. 16.—Trowels

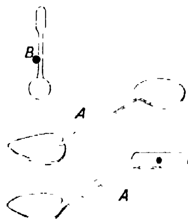

FIG. 17.—Gate cutters and gate knives.

FIG. 18.—Runner peg.

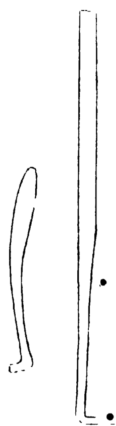

FIG. 19.—Cleaners.

Cleaners, of which fig. 19 is a type. They have one end turned up, the other being a long, flat strip, the broad side of which is at right angles with the back edge of the turned-up end.

Rammers.—The rammers used in bench, floor, and pit moulding respectively only differ in point of size. A floor pegging rammer used for the preliminary ramming is shown in *A*, fig. 20. The head is of iron, and of wedge shape, tapering from 1 inch

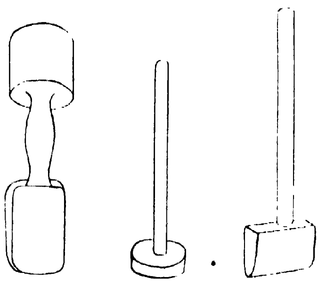

FIG. 20.—Rammers.

in width at the top to ¼-inch at the bottom. *B* is a flat rammer used for the final ramming, the head of which is flat, and 2½ inches diameter, and 1 inch thick. *C* is a combined pegging and flat rammer made of wood used in bench work.

Chaplets.—Unless bedded in the mould a core requires a support to keep it in position during casting, and for this purpose chaplets, studs, and nails are used (fig. 21). Stud chaplets are chiefly used in brass moulding.

Chaplets are of varying shapes and sizes, and are

made from sheets of sheet iron, copper, or brass riveted together by a pin or pins, the distance between the two sheets being varied according to the thickness of metal required between the core and the mould. For heavy work chaplets of cast or malleable iron are employed. Before being used iron chaplets should be tinned, or heated to redness, and allowed to cool slowly. Pipe chaplets are circular discs of sheet iron with a long stem, the end of which is either pointed or blunt. Chaplets are weighted or wedged to keep them in position. The use of chaplets should be

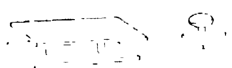

FIG. 21.—Chaplets

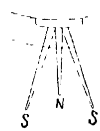

FIG 22.—Method of supporting a core by means of a nail.

avoided as far as possible, as they tend to weaken a casting, and when used the number should be limited, only what is absolutely necessary being employed.

The nails used have large flat heads and, like iron chaplets, are tinned previous to use. They are employed in iron and steel casting, and for obtaining the required thickness in pipes. In bronze and brass work, copper nails are used. Fig. 22 illustrates how a core may be supported by means of a nail in a light green sand mould. *N* is the nail, which is further supported by the two sprigs *S*, *S*.

Draw Spikes, Lifting Screws, are used for drawing a pattern from the mould. There are

several varieties; some have sharp points, and are used for wooden patterns; others a thread which screws into a tapped hole in a metal pattern, or a tapped plate on a wooden pattern.

On lifting the top part of a moulding box the suction of the sand is usually sufficient to bring away the top half of a light wooden pattern with it. This, however, is not the case with metal patterns, and they are, therefore, drilled and tapped, and a lifting screw is inserted having an eye which projects through the top part of the box. After ramming the top part, an iron bar is passed through the eye and wedged on the sides of the box, and thus on lifting the top part it brings away the pattern with it.

In addition to the foregoing, shovels, riddles, spirit-levels, straight-edges, camel-hair and other brushes, etc., are required.

§ 14.—MOULDING.

Moulding is an art that requires the exercise of considerable skill and judgment, and proficiency as a moulder can only be attained by actual practical experience. It consists of producing, in the least possible time and with a minimum of cost, a mould which shall give a casting of the desired form, and free from blowholes, shrinkage cracks, and other defects.

Moulding may be roughly divided into two classes, viz.:—

(1) Green and dry sand moulding, in which a pattern of the shape and form of the finished article is employed.

(2) Loam moulding, in which the ordinary patterns are usually dispensed with, and the mould built up of brickwork (iron tie bars being used to strengthen it if required), which is covered with loam, and the surface carefully shaped to the required form.

The making of a mould consists of several operations, any one of which may make or mar the success of a mould.

Preparing the Sand.—Before use the sand is sieved, and the following is the mesh of the sieves used for the several varieties of sand:—

Sand.	Mesh of Sieve
Floor	$\frac{1}{2}$ inch.
Facings (heavy work) . .	$\frac{1}{4}$,,
,, (light work) . .	$\frac{1}{8}$,,
Parting	$\frac{1}{16}$,,

Facing sand is sieved, coal-dust is added, and the two thoroughly incorporated by turning the mass over from top to bottom. The mass is then moistened with water, and well "trodden" with the feet.

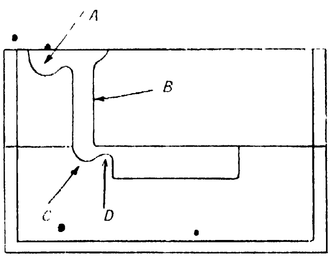

FIG. 23

Gates are passages made in the sand by means of which the liquid iron enters the mould, and they are made up of three parts: (1) a large bowl-shaped depression termed the pouring basin (*A*, fig. 23) made in the top of the flask or cope, and so situated as to admit the iron to all parts of the

mould at as nearly as possible the same time. It is shaped by hand, and at the entrance to the runner (*B*) a low dam is made; (2) a runner or sprue (*B*); (3) a gate (*C*), the sectional area of which is constricted at *D*.

Pouring Head.—To obtain a sufficient head of metal, as when the height of the sand in the top flask or cope above the pattern is small, it is necessary to employ a pouring head, which consists of a small frame filled with sand in which the pouring basin and runner are shaped. The pouring head is placed on the top flask, so that the runner is directly over the runner of the cope.

Skimming Gates, as the name implies, are employed for the purpose of removing the dirt which invariably accompanies the liquid metal so that only clean iron enters the mould, thus ensuring clean and solid castings. The principles on which they are based are either specific gravity or centrifugal force. If based on the former principle, the pouring gate is made of a larger area; if on the centrifugal principle, a chamber is formed between the mould and the pouring gate, to both of which it is connected by means of small passages or sprues.

Feeding Gates or Heads.—As already stated, molten iron on solidifying contracts or shrinks. To meet the contraction arising from the chilling of the metal during pouring and solidification, whether great or small, fresh supplies of liquid metal are made until the casting is solid. This in small castings is effected through the gates and risers, but in large castings a feeding head (fig. 24) is necessary. It is best placed over the heavy part of the casting, and to allow of

its being easily removed it is constricted at the point of connection with the casting. To keep open the contracted orifice between the feeder and casting, a wire rod (feeding rod) is worked up and down with a churning action. Care must be taken to avoid contact with the mould, and touching the sides of the passage. Fresh metal is added from time to time as required. The size of a feeder varies with that of the casting. Heavy and solid cylindrical castings are fed by carrying the mould 2 to 3 inches higher than the pattern.

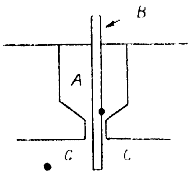

FIG. 24. *A*, feeding head; *B*, feeding rod; *C*, *C*, casting.

Risers, also termed "whistlers," are made similar to the runner of a gate, and serve as (1) a vent; (2) skimming gate; and (3), in small castings, a feeding gate. They are made in the same way as a runner, leading through the cope to the top of the casting. One or more are used, and they are placed over the part or parts where a clean surface is required.

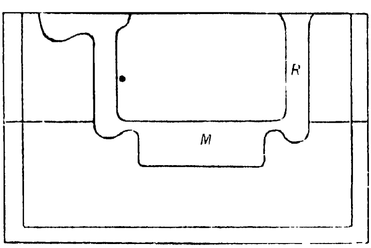

FIG. 25.—*R*, Riser.

The object of gating being the filling of the mould as rapidly as possible with clean metal and with the least amount of disturbance, the size, shape, and position of these channels are of importance. They should be large enough to allow the metal to fill all parts of the mould without the metal being chilled, and of a wide and narrow section. Placed where the runners or sprues are easily broken off; on the heaviest part of the casting—the hub of a wheel for instance; and where the natural flow of the metal will allow of the mould being filled rapidly. The area of the runner should be less than that of the gate, while a runner feeding a series of runners should have a larger capacity than the runners themselves. Runners should not be placed near parts that have to be machined. With a rectangular casting the runner is placed in the centre, and gates made in several places along its length. So also with long cylindrical castings, the gates being placed so that the metal enters the mould at the centre line. A pouring basin may have two or more runners leading from it to the mould. In casting the runner is closed with a stopper or cover until the pouring basin is filled, and frequently a small channel is cut leading from the pouring basin to the runner under the stopper, with the object of allowing the metal entering the mould to form a cushion.

Moulds are top, side, or bottom gated. The first-named has the advantage that it is readily made, and the metal in falling upon that already in the mould keeps its surface agitated and hot, thus preventing dirt or loose pieces of blacking from adhering to the sides of the mould, and reducing the tendency to the

entrapping of gases, and causing cold shorts. They are so placed that the metal falls vertically to the bottom without striking the sides of the mould. Side and bottom gates are so arranged that the metal has a clear straight run without striking the opposite side of the mould, and where the metal has the longest run. They tend to chill the metal, and for this reason hotter or more fluid metal should be used than with top pouring.

Ramming.—To enable it to adhere in the flask, to withstand the flow of the metal, and to retain the form of the pattern, the sand is rammed, and the degree of the hardness of the ramming is governed by: (1) the size and the condition of the sand. (2) the size and weight of the casting; and (3) the size of the mould. The ramming must be hard enough to compress the sand into a compact mass sufficiently dense to retain the form of the pattern, to resist the pressure of the metal and swelling of the casting. Too hard ramming gives rise to blowholes and spongy castings, and frequently the pattern cannot be removed without damaging the mould. Metal will not lie "kindly" on a hard, non-porous bed of sand. Loose ramming, on the other hand, may give rise to: (1) castings of scabby and uneven surfaces, caused by the sand being washed away from the face of the mould by the flow of the metal. (2) swelled castings. This is brought about by the sand either sinking under the weight of the metal, or being forced or bulged out by the pressure.

As it is the bottom part of the mould that has to bear the weight of the metal, it is rammed harder than the top part, and the places where the parts of

the mould separate must be hard rammed to enable them to withstand the constant handling. In ramming the best results are obtained by ramming thin layers of about 5 inches at a time.

Venting.—To allow of the escape of the air and gases, generated by the liquid iron coming in contact with the materials of the mould, passages called vents are made in the moulds by means of venting wires or rods. The proper venting of a mould is of considerable importance, and the bottom of a mould requires considerable venting, so also does new sand, and still more so sand mixed with coal. Fast pouring, and also cold (chilled) iron, necessitate much venting. In venting the vent wire should not touch the pattern. For light castings the sides of the mould need not be vented, but in heavy work the sides require venting. Cross channels are made in the bottom surface of the lower part of a drag to allow of the escape of the gases between it and the bottom board. In casting, the gases escaping from the vents should be lit as soon as possible.

Cores.—A core is a body of sand, mixed with an extra binder, moulded to the required shape, and placed in a mould so as to cut out a portion of the metal not required, or to form the internal shape of the casting. They are classified as green-sand, dry-sand, loam, and chill cores, according to the material of which they are made. They vary considerably in size and shape, according to the class of work, and may be long and proportionately small in diameter, or winding, or otherwise intricate. The making of cores is very similar to that of moulds, in that boxes or flasks are required, and like them they must be

capable of resisting the washing action of the metal, allow of the free escape of the gases. and require venting. (For cylindrical cores, tubes of the internal diameter required in the core may be used.) Evans' patent core-boxes are shown in fig. 26.

Small straight cores need no support, but long cores require to be strengthened, and for the purpose iron wires or rods (termed "core-irons") are employed, which are either straight or bent according to the contour of the core. They are bedded in one half of

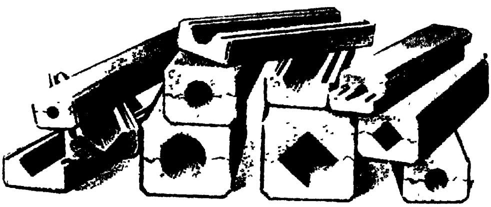

FIG. 26.—Evans' patent core-boxes.

the core throughout its entire length. The core-irons must be free from spring. Large cores may require several irons, and larger ones are supported by means of grids.

Practically all cores are dried previous to use, and are afterwards coated with blacking.

Straight cores of small diameter are best vented by placing along side the strengthening wire and parallel with it a vent wire, which is withdrawn before opening the core-box. A slightly curved core may be vented by a piece of string, and an elbow core by two pieces of string laid so that their ends slightly overlap

at the bent portion. Elbow cores of large dimensions are vented by making, along side of the strengthening wire, a channel which is loosely filled with small coke, about the size of a pea and free from dust, ashes, or cinders (this is known as an "ash vent"). For very weak cores a special wax cord is used. The wax being of a low melting point, on drying the core it melts readily, and the liquefied wax is absorbed by the adjacent sand, leaving a clear channel. In venting the aim is to establish free communication with the air at the points where the core is connected with the mould, and that the gases shall be able to move more freely towards the vents than in any other direction.

Cores are also made by the processes of "sweeping" or "strickling" (see p. 98).

Long cylindrical cores, such as used in the production of cast-iron gas and water pipes, are made by winding hay ropes or bands round a tube (termed "core-barrels" or "bars") with holes drilled in it at intervals. (The holes act as vents.) On the surface wet loam is spread, which is rubbed well into the interstices of the rope, more loam put on, and the core strickled to the required diameter while being revolved.

In some cases a pattern is of such a shape that it will itself form a core, as, for instance, a gland, and such a core is termed a "green-sand core."

What in light work is termed a "false core," and in heavy work a "drawback," is a part of a mould which is made movable to allow of its being drawn away horizontally from the pattern. Such a mould is used with a solid pattern having no core prints, but projecting portions on the side faces below the joint line —ornamental work for example.

Drying stoves for cores vary considerably in size, and for heavy cores are similar to those for drying

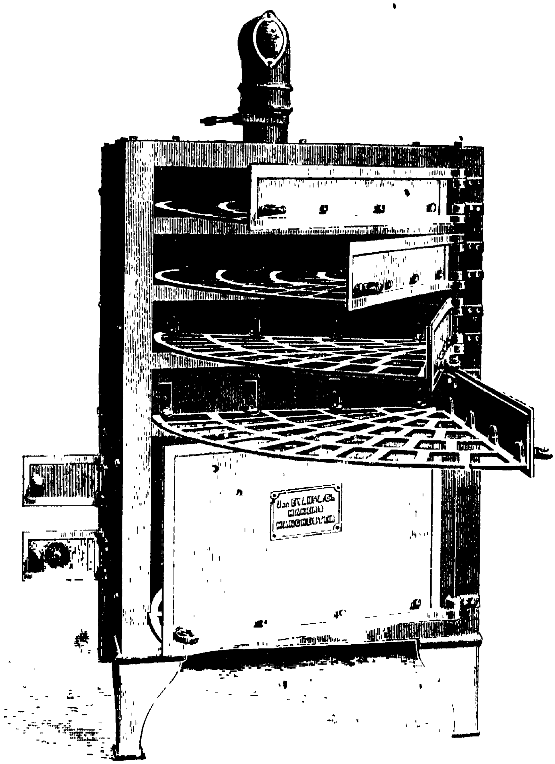

FIG. 27.—Evans' core drying stove.

moulds (see p. 106). For light work, a stove built of cast iron is used, which is heated by a fire grate

placed in the bottom. The stove is divided into several compartments by a series of perforated shelves, each of which is provided with a door, so that access to any one compartment can be made without cooling the others.

Fig. 27 illustrates an independent drying oven for small cores.

Stopping off, and extending.—It sometimes happens that a casting has to be made of less dimensions than the pattern available, and in such a case what is termed "stopping off" is resorted to. As a simple example of stopping off, a plate is required some few inches shorter than a stock pattern. A mould is first of all made from the pattern, the pattern withdrawn, and then a stopping-off piece (a straight-edge will in this case answer the purpose) is placed in the mould at the required distance, and the intervening space filled with sand, and the stopping-off piece removed. In stopping off a shaped mould, strips of lead bent to the contour of the pattern are used.

A mould may be extended or lengthened by the reverse operation, that is by attaching a piece or pieces of wood, or strips of lead bent to shape to the pattern previous to moulding.

§ 15.—OPEN SAND MOULDING.

Moulding boxes or flasks are not used in open sand moulding. The upper surface of a casting made in an open sand mould is rough, and it is, therefore, only used when one rough surface is immaterial, such as floor-plates and boxes. Patterns may or may not be

used, and if they are, they are always made of a greater thickness than that required in the casting. When no pattern is used the mould is made up to size by means of straight-edges and templets.

In moulding a plate in open sand from a pattern, the sand on the foundry floor is dug over, and riddled over the floor to the depth of several inches. Place the pattern on this heap of sand, and bed down until the sand underneath the pattern is uniformly compact, and a spirit-level placed on the upper surface of the pattern shows it to be perfectly level. When this is

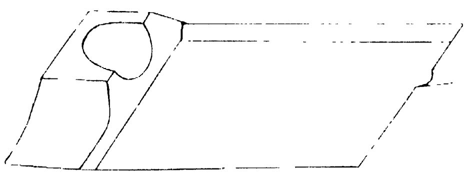

FIG. 28.– Open sand mould

attained, weight the pattern down, and build up or tuck sand around the edges. Strike off the sand level with the top of the pattern with a straight-edge, and at one side make a small basin or runner, the bottom of which should be just level with the top of the pattern. On the side opposite to the runner, cut an overflow channel of such a depth that when the metal overflows, the mould will give the required thickness of metal in the casting. On withdrawing the pattern the mould is ready for pouring. In open sand work the bed is seldom vented, unless the casting is a thick or deep one.

To do away with the necessity of levelling for each mould, as is the case with the foregoing method of

moulding, it is usual when more than one casting is required to strike a level bed, the surface of which will form the bottom of the mould. To make this bed, take two straight-edges, and place them parallel to one another at a distance apart to form its outside boundaries. The straight-edges must be made perfectly level in the direction of their lengths, and also level with each other. (The last named is ascertained by placing a third straight-edge across them and placing a spirit-level in the centre of it.) Ram the two straight-edges in place, and fill the space between them with riddled sand. Lightly ram the sand, and continue the addition of the sand, ramming with each addition, until it reaches a little above the level of the two straight-edges. Strike or strickle off the sand level with the tops of the two straight-edges by drawing a straight-edge across them. On this bed place the pattern face downwards, and build up sand around its edges. Make a small pouring basin, and cut an overflow channel.

Sweeping.—In sweep work a mould is shaped by a board (termed a "sweep"), cut to the required shape, arranged to revolve around a vertical spindle working in a central socket, placed some distance below the face of the mould bed.

Strickling.—In strickling, a mould is made up to the required shape by means of a board (called a "strickle"), which is drawn across guides. A strickle may be either a straight-edge or a board cut to the required shape.

The making of a level bed is practically an example of strickling; the two straight-edges being the guides, the third one the strickle.

§ 16.—GREEN SAND MOULDING.

In green sand moulding the mould is not dried, or otherwise prepared, previous to the metal being poured into it. Generally in green sand moulding closed moulds are employed, and two methods are followed—(1) in which the pattern is turned over, and (2) in which the pattern is bedded-in For the best work, and also in much repetition work, the first method is used, as, generally speaking, there is less risk of unequal ramming and its attendant evils, and of the casting becoming distorted and strained than when bedding-in is followed. Further, the construction of the mould requires less skill.

Turning-over.—As a simple example of moulding, a casting having flat sides and no re-entering angles is required. Place the pattern face downwards on a turning-over board, and over it place the bottom part of a moulding box or flask—drag—with the sockets down. Over the pattern sprinkle a layer of a mixture of coal-dust and floor sand to a depth of about $\frac{1}{2}$ inch, and fill the box with riddled floor sand, and lightly ram. Strike or strickle off with a straight-edge the sand level with the edges of the box, and sprinkle on a layer of sand, and bed on a bottom board by moving it backwards and forwards until it rests level on the edges of the moulding box. Remove the bottom board, make channels in the sand, and vent the mould well with a vent wire. Replace the bottom board in position and turn over the whole by gripping the two boards together. Remove the turning-over board, sleek the sand around the pattern, blow off any loose sand with a bellows,

and sprinkle over the surface a little parting sand. Blow off the surplus, and dust a little parting sand over the joint (the place where the mould parts). Place the top half of the moulding box (cope) in position, put a runner peg in the widest part of the joint, add sand, ram, and continue the addition of sand and ramming until the box is full. Strickle off the sand level with the edges of box (or the cross bars), and well vent with a vent wire. Remove the runner peg, and widen the top of the runner so as to make a small basin. Remove the cope, turn it over, and lay it on a board. Dust over the face forming the top of the casting with a little plumbago or charcoal, and blow off the excess. In the sand in the bottom box cut a gate so that it connects with the mould and the runner. Blow off any loose sand, and slightly wet the joints round the pattern Drive a draw spike into the pattern, rap it lightly, and remove the pattern. Place the top box (cope) in position over the bottom one, and cotter or weight it to keep it in position.

In moulding a pattern which has fine detail work, strong facing sand is sieved over the pattern, and the box filled with sand, etc., as before To give to the casting a fine skin what is termed "printing" is followed. This consists of dusting over the surface of the mould, after the pattern is withdrawn, with plumbago, and replacing the pattern exactly in its former position, and pressing it down.

A pattern made in two or more parts is held together by pins and sockets (dowels), and in moulding from a two-part pattern, one-half is laid on a turning-over board, and moulded as before, and turned over.

Place the other half of the pattern in place, and dust parting sand over the surface of the mould Put the top box in position, insert a runner plug, and ram with sand. Remove the top box, which should take the upper half of the pattern with it gate, etc., as before.

A solid pattern, having no flat surfaces, cannot be laid on a flat board for turning over, and such a pattern is moulded by using what is termed an "odd side" or false top part.

Place the top part of the box to be used on the floor, and fill it with sand, and tread. After strickling off the excess of sand with a straight-edge, cut out a rough outline of the pattern, and bed in the pattern to its centre line, packing the sand well with the fingers Place the bottom part of the box in position, fill and ram with sand, cotter or clamp the two parts together, and turn over. Lift off the top part, and knock out the sand. With a trowel, joint (cut away) the sand in the drag to the level of the exact centre line of the pattern, make the parting, and place the top part of the box in position, set the runner plug, and ram up, etc.

In repeat work of the same character, the moulder frequently makes use of an odd side, made either of sand or plaster of Paris. A sand odd side is used when only a few castings are wanted, but when a permanent one is required a plaster odd side is made.

To make a green sand odd side, a top part is rammed up, the pattern sunk in to the required depth, and the joint made. A dry sand odd side is made in the same way, except that after jointing it is black washed and dried. An oil odd side is made

by adding one part of litharge to twenty parts of nearly new dry sand, thoroughly mixing the two, and adding sufficient linseed oil to bring the mixture to the consistency of a moulding sand. After ramming up and jointing, an oil odd side is allowed to harden in the air for about twenty-four hours.

In making a plaster of Paris odd side, make a sand odd side, and after jointing, oil or grease the pattern, place a second box part in position on the one containing the jointed pattern, and fill in the joints between the two with a slurry of black sand and water. Mix plaster of Paris with water to a consistency of a thick cream, and pour it over the pattern until the box is full. When the plaster has hardened, turn over, lift off the sand odd side, and draw the pattern. Remove any sand adhering to the plaster mould, and coat the face with varnish, and dry.

Moulding in three part boxes requires the employment of divided patterns, and in describing the procedure followed, the moulding of a sheave wheel or grooved pulley is taken.

The pattern is divided through the centre longitudinally and the halves dowelled together. Bed the lower half of the pattern on an odd side, as described on p. 101, making the joint down to the outer edge of the rim of the pattern, ram, and turn over. Place the top half of the pattern in position, and put the mid part on the bottom part. Fill the mid part with riddled sand, which tuck with the fingers well into the groove of the pattern until the edge of the sheave is reached, and then ram and joint. Place the top part in position over the mid part, set a runner plug so that it is over the hub of the wheel,

ram and withdraw the runner plug, and make a basin. Remove the top part, and draw the upper half of the pattern; then lift off the mid part, and draw the lower half of the pattern. Replace the mid part and the top part.

Bedding-in.—In bedding-in the lower part of the pattern is moulded in the sand of the foundry floor instead of in a drag, and the upper part covered or enclosed in a cope, mid parts being used as required.

To bed-in, a hole deeper and wider than the pattern is dug in the foundry floor, and filled with riddled sand, over which facing sand is sieved. (The sides of the hole are sloped so as to be wider at the top than at the bottom.) On this bed the pattern is laid, pressed and gently hammered down until comparatively level and solid, when it is weighted down, and rammed. Having sleeked over the floor over an area larger than what will be covered by the cope, a layer of parting sand is spread over it, and the cope placed in position. Facing sand sprinkled over the pattern, a gate pin placed in a suitable position for running the casting, and the cope rammed with floor sand. After ramming the cope, but before lifting off, it is staked at the four corners, to ensure that when closing the mould it will be replaced in exactly the same position. The stakes should be of ample length, and driven vertically for at least two-thirds of their length into the ground, with the projecting ends flush up against the sides of the cope.

Loose Pieces.—A pattern is usually drawn vertically from the mould, but owing to some overhanging part, this is not possible in all cases without tearing the mould. To overcome the difficulty the pattern is

made with loose or detachable pieces, which, while the mould is being rammed, are fastened to the pattern by wire pins, screws, or other fastenings easy of withdrawal. In moulding a pattern with loose pieces care must be taken that the holding pins or screws be withdrawn as the ramming proceeds.

Sometimes a green sand mould is skin dried immediately before casting, in which case a loamy facing sand is used, and, as with dry sand moulds, the mould blackened.

§ 17.—PLATE MOULDING.

Either wood or metal plates are used, and, if for hand work, they are provided with snugs having holes corresponding to the pins in the moulding boxes. A flat pattern is attached to one surface of a wood moulding plate by means of wood screws from the other surface, and wood patterns of the runner gate fixed and attached in the same way, and the runner and gate connected with the pattern. On the plane surface of the plate a small boss is fixed in the position where the runner peg should come.

In moulding, the plate is placed with the surface of the pattern and the drag uppermost between two moulding boxes, the drag rammed up as usual, and the whole turned over. The runner peg is set over the boss, and the top part rammed up. After ramming, the top part is lifted off, and the plate removed. On putting the top part in position over the drag the mould is ready for casting.

A pattern not having a flat surface, but divided in its centre, is mounted in halves on either side of the plate.

A pattern is attached to a metal plate in the same way, or the plate and pattern may be cast in one piece.

§ 18.—DRY SAND, LOAM, AND BENCH MOULDING.

The methods employed in dry sand moulding are practically the same as in green sand moulding, the only essential differences being that the moulds are dried previous to being used, a loamy sand is used next to the pattern, and this is backed with moulding sand. They are generally made in boxes.

Dry sand moulds are more porous than green sand, and they give smoother and sounder castings as they give off less gas on pouring the metal

The sand of which the mould is made must be of such a nature that, after drying it will yield a porous but not friable mould.

A dry sand mould may be rammed harder than a green sand one, as a more open sand is used and the moisture expelled on drying.

The extent to which a mould is dried varies with the character of the mould, and the metal being cast, whether iron, steel, or brass. For steel castings the mould must be thoroughly ("bone") dry, while for iron and brass castings the mould may be either bone or skin dry (that is the surface dried to the depth of about half an inch).

Dry sand moulds are made in iron moulding boxes.

After drying, a dry sand mould is given a coating of (or faced with) blacking, which in the case of a bone-dry mould is always applied wet, and either wet or dry to a skin-dry mould, and is applied either

before or after drying the mould. If the latter, the mould must be at a temperature sufficiently hot to dry the facing.

The methods of drying a mould vary. A mould made in the floor must be dried there, and for the purpose fire baskets (or "devils") are hung in the mould, or large fires built directly over and surrounding it. Moulds made in boxes must be dried in their boxes, and for this purpose drying stoves are used. The ordinary stove consists of a firebrick chamber with fire grates (coal or coke fed) varying in number with the size of the stove, and fed either from the inside or externally. As the drying of the moulds is effected by means of heated air, flues are built at or near the floor level at the opposite ends to the fire grates, and connected with a stack. The stove is provided with a set of rails and carriages on which the moulding boxes are loaded, and carried in and out of the stove. Gas-heated stoves are also in use.

Loam Moulding - This method of moulding is generally used for large castings—such as engine cylinders, propeller blades, sugar pans, and where a casting can be made more economically this way than otherwise. Patterns are largely dispensed with (this is one of the advantages of the method), and in many instances none at all are used, or at most a few parts of patterns, or a skeleton of the form required.

A loam mould is built up roughly of brickwork on a bottom plate of a shape suitable to the casting, the bricks being placed at intervals apart, with the spaces between filled with ashes for venting purposes. Iron plates bent to shape are placed at intervals as required to strengthen the structure. This structure is then

covered or faced with loam, and worked up to the required shape by means of sweeping boards and strickles. For circular sections moulded vertically, sweeping boards attached to a spindle or striking bar are used, and for surfaces that can be rubbed lengthwise strickles working against straight or curved guides. Any projecting parts of a casting are made by embedding in the mould, while it is being built, patterns of the parts. The mould when completed is dried, either in the pit or transferred to a stove. All loam moulds are run from the top.

Three varieties of loam are used: (1) building loam, which is black sand made into a slurry with water or clay-wash; (2) coating loam; and (3) finishing loam, which is the fine sievings from coating loam. The loam is milled with water or clay-wash to the proper consistency, and during the grinding, cow-hair and manure added to make it adhere to the mould, and for opening purposes.

A loam mould can only be used once, and this method of moulding is both troublesome and expensive.

Bench Moulding.—The moulds for light iron, steel, and brass castings may be conveniently made on benches or tubs, and in this class of work the methods followed are exactly similar to those used in green sand moulding. Either moulding boxes, interchangeable and well fitted, or snap flasks are used, and for divided or flat patterns a turning-over board.

When a quantity of small castings are required from the same set of patterns, time and labour may be saved by making a pattern of the runner and gate. In moulding, the runner pattern is first placed on the

board, and the patterns of the castings placed in contact with each gate, and the mould rammed. After turning over, the top box is placed in position, a runner plug set over the gate pattern, and the mould completed as usual.

Several similar patterns may be joined together in such a way as to form a single pattern, and the connecting pieces the gates. This is termed a "gated pattern."

§ 19.—MOULDING MACHINES.

Moulding machines are used both for the making of cores and green sand moulds, and it may generally be said that, where repeat work of a simple kind is executed, the quality of the product is equal, if not superior, to hand moulding. They answer well when the rammed work can be easily withdrawn, with shallow patterns, and when the mould is easy to ram, but for work of intricate shapes, or re-entering angles, they are not suitable.

§ 20.—CASTINGS.

Chilled Castings.—For certain purposes (such as dies, wheels, chilled rolls, etc.), it is desired to have the surface or part of a casting very hard so as to resist wear, with the body relatively soft and tough. This is effected by placing in the mould at the place where the hardness is required what are termed "chills," which are moulds made generally in cast iron of those parts of the casting it is desired to harden. The molten metal in direct contact with the

metallic portion (the "chill") of the mould is rapidly cooled, thus preventing the separation of the carbon as graphite, as would occur under ordinary conditions of cooling, hard white iron being formed, while the body of the casting, which cools more slowly, remains relatively soft and tough. As a rule, chills are used in conjunction with green sand moulds, and any iron that chills will make satisfactory chills.

The depth or thickness of the chill obtained will depend on the weight of metal in the chill employed, and the greater the weight or mass of metal in the chill the more rapidly will the heat be drawn away from the molten metal coming in contact with it, and, therefore, the deeper the chill. While chills should be sufficiently heavy (or thick) to produce the necessary depth of chill, they should not, on the one hand, be too heavy, as the tendency to crack is increased, and, on the other hand, not too thin, otherwise the chill will not be sufficiently deep. Where skin chilling only is required, flat plates from ½ inch to 1 inch thick will answer the purpose if for plane surfaces, or if for curved surfaces, shaped to fit the curvature.

The surface of a chill which comes in contact with the casting is freed from tool marks, etc., frequently by being machined, and as the liquid metal will not lie quietly or the blacking adhere on such a smooth surface, the smoothness is removed by uniformly rusting it. With this object the surface of the chill is slightly wetted with a saline solution—urine, or a dilute solution of sal-ammoniac may be used—and exposed to the weather. No crust of rust must be left on, only a thin, uniform, adhering coating.

A chill is bedded against the pattern, and rammed up with the mould, while to prevent the hot fluid metal from sticking to and damaging it, the surface is coated with plumbago, or given a wash of black-lead with a little clay. A chill is always heated before being placed in the mould, as otherwise there is danger of fracture from the sudden contact

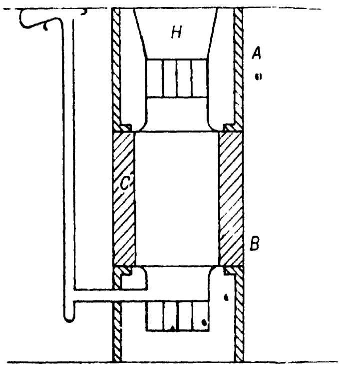

FIG. 29.—Mould for chill roll.

with the hot metal, and the possibility of moisture depositing on the surface of the chill and causing trouble. A mould is cast before the chill has time to cool.

In casting, the mould should be filled as rapidly as possible, and, therefore, large gates are necessary, so as to admit a large stream of metal to the mould. The position of the gates and the direction in which the metal flows must be such that the latter does not impinge on the face of the chill. While the casting

metal should be sufficiently hot to ensure the rapid filling of the mould, it should not be hotter than necessary, as the hotter the metal the greater the liability of the chills to fracture and scour.

Fig. 29 shows the mould of a chilled roll. The necks and wobblers are rammed up in dry sand from patterns in the boxes *A* and *B*. The latter are provided with internal flanges for attaching to the chill *C*. The mould is run from the bottom through a whirl gate to the lower neck, as shown. *H* is the feeder head.

Malleable Castings.—Malleable castings differ from ordinary castings only in that they are less brittle and usually stronger. As cast, however, they are hard and brittle and the change in their properties is the result of the after-treatment to which they are subjected. There are two varieties of malleable castings, which differ only in the different principles involved in their manufacture, viz., (1) ordinary malleable (Reaumur), and (2) "Black Heart."

Ordinary Malleable ("Reaumur") Castings.—In this process the object is to eliminate the carbon, which exists in the original casting in the combined state, resulting in material similar to wrought iron. This is brought about by heating ("annealing") the castings in the presence of an oxidising material—oxide of iron in the form of iron ore.

The iron used is a special variety of white iron, obtained by refining hematite iron, low in silicon and phosphorus, the first named not exceeding one per cent. M'William and Longmuir give the following analysis of an iron:—

Total carbon	3·50	%
Silicon	·5 to ·9	„
Sulphur	·25 to ·35	„
Phosphorus	·05 to ·08	„
Manganese	·10 to ·20	„

See also Analyses of Pig-irons, p. 21.

The moulds are made in green sand, of a fine grain to obtain a good surface, well vented, and to make provision for the high contraction of white iron larger gates and risers are used than in grey casting. The iron is melted in crucibles, the air furnace, or in the cupola. Although in crucible melting there is more certainty of the composition of the iron the method is limited by the weight of the casting, and it is high in fuel consumption For light work, and where high-grade work is not required, the cupola is used. it is not, however, so suitable for heavier work, and to obtain better uniformity of metal the iron should be charged in small pieces.

Either when cold or just set the runners are detached: the cold castings barrelled to remove the sand, or if too delicate to allow of this, treated with dilute acid, and subsequently washed in water. They are then packed in pots or boxes with iron ore, and after luting on the lids with fireclay, the pots or boxes placed in the annealing oven or furnace, and heated at a full red heat for a period of from eight hours to as many days, and when annealing is complete, allowed to cool slowly. The ore used is a variety of red hematite, broken up finely and sieved, and on account of its being too active it is not usual to use all new ore, but a mixture of one part new to several parts of old.

The pots or boxes are generally made of cast iron, and vary in size and shape according to the castings to be treated. The annealing oven or furnace is usually a rectangular chamber of a size to contain from one to eight tons of castings, coal, gas, or oil fired, generally the first named.

Fig. 30 shows a simple form of coal-heated an-

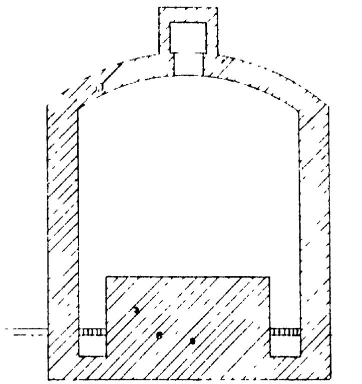

FIG. 30.—Annealing furnace.

nealing furnace, in which the flames enter at the floor level, passing toward the centre, and the products of combustion escaping by the flue in the top. The heat is gradually raised to the proper annealing temperature, which according to Turner is 850 to 900° C. The length of time the casting is kept at the annealing temperature, that is annealed, is dependent upon the thickness of the casting, thin castings requiring a shorter period than thicker.

"*Black Heart*" *Castings.*—The object in this pro-

cess is not to eliminate the carbon, but to decompose the carbide of iron into finely divided, free carbon ("annealing" or amorphous carbon) disseminated through the iron. The process is similar to the Reaumur, excepting that the castings are packed in scale, or sand, or bone dust instead of iron ore. The iron is usually melted in the cupola, and according to McWilliam and Longmuir should approximate the following composition:—Carbon 3·0 per cent., Silicon 0·5 to 1·0 per cent., Sulphur 0·05 per cent. maximum, Phosphorus 0·10 per cent. maximum, Manganese not above 0·50 per cent.

Cleaning or Dressing Castings.—To clean or dress a casting, the gates, runners, etc., are knocked off, and then the adhering sand removed by rapping with a hammer, followed by brushing with a wire brush, or scraping with an old file.

Small iron, steel, or brass castings may be cleaned in a tumbler or rattler. This is a revolving barrel into which the castings are packed, and by rubbing against each other the sand is removed. After tumbling, the cores are cleaned out, and the gates ground off.

A casting that cannot be cleaned by tumbling, and has to be machined, is treated with acids. Dilute sulphuric acid is generally used, and the casting is either soaked in it, or laid in a wooden tray, and the acid poured over it at intervals. The action of the acid is to eat into the skin of the casting, and thereby loosen the sand. (Hydrofluoric acid may also be used, in which case the sand only is dissolved off.) After treatment with acid the casting is washed with water. This method is not suitable for steel castings.

A method of cleaning, applicable to all classes of castings, is by means of compressed sand-blast, directed on the casting.

ANNEALING.—Iron and steel castings are annealed to remove internal stresses, which are apt to cause fracture, and also to render them soft and easily machined. The treatment consists of heating to a good red heat, and cooling slowly. For steel castings Arnold recommends for general work heating up to about 950° C., keeping at this temperature for about 70 hours, and cooling (luting up the furnace) as slowly as practicable. To minimise the scaling, the castings should be packed in lime in covered cast-iron boxes.

Defects in Castings.—A faulty casting may be due either to the mould or to the metal, and the most common defects met with are —

Short pours, that is, insufficient metal to fill the mould.

Scabs are wart-like projections on the surface of a casting, and in green sand work are usually due to faulty venting, too much moisture in the sand, or too hard ramming. In loam and dry moulds, scabs are generally the result of insufficient drying

Cold shuts.—When a casting shows the junction of two streams of metal, the casting is said to be a cold shut. The cause is, pouring the metal at too low a temperature, or not sufficiently rapid. Want of fluidity in the metal is also a cause of cold shuts, in which case a small increase of the silicon, and possibly of the phosphorus, and a decrease of the sulphur and manganese will generally put matters right.

Dirty castings may arise from dirty metal, or dirty runners, risers, moulds, etc. These must be free from loose sand. A facing that shells off, or gathers as a dross in front of the metal, also gives rise to dirty castings.

Rough surfaces.—Sand wanting in refractoriness, or too coarse, may be the cause of rough surfaces, but more generally they are due to the metal being either too hard or poured too hot.

Blowholes are due to: (1) the mould; (2) the metal; and (3) a combination of the two. In the majority of cases blowholes in grey-iron castings are invariably due to the mould, and the cause is too hard ramming, wet sand, or want of venting. Blowholes due to the metal are commonly caused by too little silicon; hard, white, sulphury metal in particular giving rise to blowholes.

Fins.—These are projections on a casting, due to the improper jointing of the moulding boxes.

Shrinkage cracks may arise from uneven cooling, metal of an unsuitable composition, or a faultily designed casting. If due to the metal, the usual remedy is the reduction of the sulphur and manganese in the mixture, or the addition of a little more silicon. A reduction of the scrap answers the same purpose.

Porosity or sponginess is generally due to a high percentage of graphite in the form of large flakes. The addition of steel or wrought iron to the mixture, or adjustment of the silicon, is the remedy.

Faulty design.—Iron during solidification develops a crystalline structure, and, unless a casting is designed with a due regard to the formation of the

crystals, its strength may be influenced The crystals grow in a direction perpendicular to the cooling surface, and it follows that a plane of weakness will develop at every sharp corner As an illustration, in the rectangular casting, fig. 31 the two sets of crystals cross on a line which bisects the angle, and where these crystals meet a plane of weakness is set up. On the other hand, if the cooling surface is curved, the crystals will interlace, and so yield a strong casting. For this reason all sharp corners, or

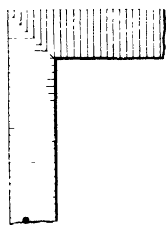

FIG. 31.

re-entering angles, should be avoided as much as possible.

Steel Casting -Steel casting does not differ materially from iron casting, but as the temperature of the metal is much higher, a more refractory sand has to be used for the moulds The castings are made from steel melted or made in crucibles, the open-hearth furnace, both acid and basic, and small converters, such as Tropenas, and either green sand or dry sand moulds are used.

For making green sand moulds, ordinary floor sand strengthened by the addition of a loam sand is used,

and the cores are made from the same material. The analysis of a "composition" for dry sand moulds is given on p. 39.

Harbord (*Metallurgy of Steel*) gives the following analysis as typical of some steel castings:—

Description of Casting.	Carbon.	Silicon.	Manganese.	Sulphur and Phosphorus
				%
Rudder frame	·16	·49	·576	below
Shaft bracket .	·21	·53	·63	·06
Eccentric rod .	·20	·361	..	in all
Pivot-plate . .	·40	·326	...	cases.
Casting . .	·47	·501	...	.
Roller path .	·33	·501	..	...
.	·22	·42	·594	...

Briefly, the process of melting crucible or pot steel is as follows:—The crucible or pot, made either of fireclay or of graphite or plumbago, previously well dried and annealed, is placed in a hot furnace upon a stand of fireclay resting on the fire-bars, and the fire built up with coke to the level of the top of the pot. In about the course of an hour the pot is ready for the charge, which is put into the pot by means of a wrought-iron funnel termed a "charger," then the lid put on the pot, and the furnace filled in with coke.

After the fire has burned for some time, it is poked down towards the fire-bars and more coke added, and when this has burnt off, the lid of the pot is removed and the pot searched with an iron rod to see whether the charge is completely melted. If this is not the

case, the lid is replaced and the fire again made up with coke, and the operation repeated until the charge is melted. When melted and sufficiently "killed" or "dead melted"—that is, allowed to remain in the furnace for a sufficient time after it has become fluid—the pot is withdrawn from the furnace, the lid removed, the slag skimmed off the surface of the liquid steel, and the metal poured

As in iron founding so also in steel founding the casting temperature of the metal is all-important, and will vary with the size of the casting, a hotter metal being required for small intricate castings than heavy, thick ones. If the temperature of casting is too low there will be the danger of the moulds not filling and the surface of the casting will be defective, while, on the other hand, too high a temperature will cause pipes and unsoundness, due to uneven contraction. Speaking generally, provided the metal is sufficiently fluid, too low a temperature is better than too high.

The three chief defects met with in steel castings are (1) blowholes, (2) pipes, and (3) segregation. Blowholes have been dealt with under "defects in iron castings." A pipe is a cavity due to shrinkage, caused by contraction. Segregation is the separating out and gathering together of certain of the constituents of the metal. These are generally the more fusible of the constituents, and therefore the last to solidify.

Otto Beckmann gives the following as the usual composition of steel for[1]:—

[1] *Giesserei Zeitung*, and *Iron and Coal Trades Review*, May 14, 1909.

	Carbon.	Silicon.	Manganese.
	%	%	%
Small machine parts	·5	·25	·50
Large machine parts	·1 to ·4	·2 to ·4	·5 to ·8
Hard pieces for edge runners, Ore crushers, etc.	·8 to 1·0	·2 to ·4	·5 to 1·0
Shipbuilding material (stem posts, rudder frames)	·2 to ·4	·3	·5
Switches, Press cylinders, etc.	·7	·4	·8

Brass, Bronze, and Phosphor-bronze Casting.—*Brass.*—In composition the brass used for castings varies considerably; it is dependent to a large extent upon the use to which the casting is put, and the colour required Commercial brass not only contains copper and zinc, but also the impurities present in the separate metals, although to a lesser extent. The most common of these are tin, lead, iron, and arsenic, and although they may be looked upon as impurities, yet they are sometimes purposely added to obtain certain results. For instance, the addition of 1 to 2 per cent. of lead, to brass that is to be turned or filed, gives sharpness to the metal, while the addition of a small quantity of tin increases the hardness.

Brass moulding differs but little from iron moulding. A finer sand, however, is used, and the joints are made smoother. For small castings the brass is melted in a crucible (for type of furnace see fig. 1), and where a large quantity of metal is required an air or reverberatory furnace is used (see p. 47).[1]

[1] Any loss in melting—chiefly zinc—must be made good.

The melting-point of brass is less than the mean of its constituents, and lower than that of iron, and in melting the metal care must be taken that the temperature be not raised too high or the operation unduly prolonged, or else loss of zinc through volatilisation will take place. The air should also be excluded as much as possible to prevent oxidation of the zinc, which is done by covering the metal with a layer of charcoal or anthracite or any substance having no chemical action on the metal.

In making alloys the metal of the highest melting point is usually first charged, and when it is partially fused the other metals in the order of their fusibility added: zinc when all the others are molten.

As with iron and steel the temperature at which the brass is poured is of considerable influence, and if too hot the castings will be porous, while if too cold the mould will not be filled.

In making brass, the copper, contained in a crucible[1] and covered with a layer of charcoal or anthracite, is first of all melted, the zinc[2] then added, and the contents well mixed by stirring with a stick.

Bronze.—The remarks on brass casting, etc., apply equally to bronze.

The alloy is prepared by first melting the copper, and then adding the tin or tin and zinc, as the case may be, and stirring.

[1] Or a reverberatory furnace, if a large quantity is required. In melting in a reverberatory furnace, the furnace must be worked with a smoky flame, and the surface of the metal well covered with charcoal or anthracite. Zinc is not added until the other constituents are molten.

[2] The zinc should be plunged below the surface of the metal.

Phosphor-bronze is prepared by melting copper and tin in a plumbago crucible under a cover of charcoal or anthracite, and when melted adding a certain quantity of phosphor-copper or phosphor-tin, or both.

For small castings green sand moulds are used, and for large castings the mould is dried, and coated with a mixture of blacklead and water.

Analyses of Alloys.[1]

	Common Casting Brass.	Naval Brass.	Gun-metal	Ordinary Phosphor-bronze.	Phosphor bronze (Bearings).	English Standard Brass	Aluminium Brass	Manganese Bronze.	White Brass.
Copper . %	60·0	61·0	86	90·0	79·7	70	60	57 – 60	10 40
Zinc ,,	34·0	38·0	4		9·5	30	39	40 37·3	90 60
Lead ,,	6·0								
Tin . ,,		1·0	10	9·6	10·0			1 – ·7	
Phosphorus ,,				·4	·8				
Aluminium ,,							1	·3 – ·5	
Iron . ,,								1·5 1·5	
Manganese ,,								·2	

[1] M'William and Longmuir, *General Foundry Practice.*

Composition of Alloys.[1]

	Copper.	Tin.	Antimony.	Zinc.	Lead.	Phosphorus.	Nickel.	
	%	%	%	%	%	%	%	
Slide valves . .	84·50	10·00			5·00	0·50 [2]		
Gun-metal, Admiralty specification.	88·00	10·00		2·00		.	.	Valve seatings, bushes, regulator slides, slide valves.
Injector metal .	84·00	8·50		5·00	2·50			Injectors, ejectors, gauge cocks.
Yellow brass . .	67·00			30·00	3·00			Cab-rings, name-plates, etc.
Phosphor-bronze .	89·50	10·00				0·50 [2]		Repairs to heavy machinery, mill bearings, wheels, pinions.
Brazing metal . .	84·00			16·00				Pipe flanges, collars, etc.
Telegraph metal . .	80·00	5·00		7·50	7·50			Small castings.
White metal, "A"	4·00	82·00	14·00				. .	Lining bearings on the pinion and commutator ends of motors.
,, ,, "B"	3·00	11·50	13·50		72·00		.	Lining axle-boxes, radial wheel brasses, reversing shafts, etc.
,, ,, "C" .	10·00	80·00	10·00					Lining big end brasses, coupling-rod bushes, cross-heads, etc.
,, ,, .			8·00		92·00			Packing ball-joint water pipes.
,, ,, .		17·00	13·00		70·00		. .	Metallic packing.
,, ,,		15·00	15·00		70·00		.	Carriage and waggon bearings.
Ordinary axle-box bearings.	80·00	5·00			15·00		. . .	
20-ton waggon bearings.	64·00	5·00			30·00		1·00	

[1] Compiled from a paper by George Hughes, on *Non-Ferrous Metals in Railway Work*. Institute of Metals, 1911.
[2] Added as 4% of 15% phosp

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